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Review and Assessment of Deep-Well Injection of Hazardous Waste. Volume IV Appendices E, F, G, H, I, and J

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Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Solid and Hazardous Waste Research Div

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16. ABSTRACT

This four volume report is a review and assessment of the adequacy of deep-well waste injection systems to receive hazardous wastes and to define what effects that these wastes will have upon the environment when injected into subsurface reservoirs. All aspects of deep-well injection systems have been touched upon.

A comprehensive bibliography, chemical waste profiles, deep-well inventory, case histories, microbiological research, deep-well and hazardous waste research, legal aspects and an inventory of statues and regulations governing waste injection are discussed in the text and detailed in the appendices.

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Volume IV - Appendices E, F, G, H, I & J

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic efforts of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This contract was supported by the EPA to provide a comprehensive review and data compilation of deep-well injection as a control and disposal technology for hazardous waste. Because of the large amount of information resulting from this contract, the report is divided into four volumes. Readers interested only in the general information about deep-wells are referred to Volume I. Those interested in the detailed data compiled during this work are referred to the remaining volumes in addition to Volume I. The information is providing input into the EPA's program for assessing control technologies available for managing the Nation's large quantities of hazardous materials.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

A review and analysis of the available information related to deep-well injection, and an assessment as to the adequacy of this method for managing hazardous wastes and ensuring protecting the environment was made.

One hundred-five deep-well related research projects were identified and hazardous waste research projects numbered 186. More than 1,000 papers related to deep-well injection of industrial waste were reviewed.

Geologic and engineering data are available in many areas to locate, design and operate a deep-well system receiving hazardous wastes. The most serious problems encountered are because of failure to use available geologic information and accepted and proven engineering practices in design and completion. A small group of waste chemicals with high human and ecological hazard ratings, little known degradability characteristics or long persistence times are identified as undesirable for injection unless containment within the host reservoir is certain.

There is a paucity of information on salaquifer chemistry, and the chemical and microbiological reactions of waste within a receiving salaquifer. Monitoring of deep-well systems needs to be developed into a predictive tool to be fully effective.

State statutes and regulations vary greatly on deep-well injection. To alleviate any problems arising from the use of interstate aquifers for injection, and for more effective management and control of deep-well systems, a standardization of regulations is considered necessary.

This report was submitted in fulfillment of EPA Contract 68-03-2103. The report is comprised of 4 volumes; the main text, Appendices A through C, Appendix D, and Appendices E through J. Volume IV is comprised of Appendices E, F, G, H, I, and J. Appendix E provides limited case histories of actual industrial waste injection well operations and provide examples of unacceptable and acceptable operations.

Appendix F discusses recent research on microbiological aspects of deep-wells. Appendix G is a summary of research related to deep-well injection, while Appendix H is a summary of research dealing with treatment of hazardous wastes. Legislation, regulations, and policies governing deep-well injection operations are provided in Appendix I. Appendix J was added by EPA so that readers would have the benefit of clarifying information that resulted from review of this document. Other volumes provide the main text and additional appendices of detailed data.

As a result of EPA review of this document, there were a number of questions and issues raised as to the conclusions made versus those warranted based upon available information. The user is referred to Appendix J for additional information resulting from this review and the contractors' response to that review.

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SECTION XI

APPENDIX E - CASE HISTORIES

EPA REGION III

Well A

Source and Nature of Waste -

The waste liquid was sulphite liquors from paper mill operations with the following characteristics: specific gravity = 1.02, pH = 5.3; alkalinity to pH 4.5, 1500 mg/l as Ca; acidity to pH = 8.3, 1900 mg/l as Ca; suspended solids = 225 mg/l; NH_3 = NIL; total dissolved solids 5 percent; hardness total as $CaCO_3$ = 200; Ca as $CaCO_3$ = 80' MG as $CaCO_3$ = 100; total sulphate = 1.75 percent; Cl = 270 mg/l.

Surface Equipment -

Few details are available regarding surface equipment other than that injection pumps were used capable of injecting the required volumes at a well head pressure of about 8.6 MPa (1250 psig).

Well Completion and Geology -

The wells were completed with 7" casing. 4-1/2" injection tubing was installed. The 7" casing was cemented to within 253 m (830') below the top of the hole.

Three wells constituted one system. The first well (PA-2) was completed in the Bass Island Formation from 491-515 m (1611-1692') and from 627-702 m (2057-2302'), tested, and put into operation in 1964. In 1964 a second well (PA-3) was completed to the basement rocks, from 1803-1814 m (5914-5952'), tested and put into use. The injection intervals used were the Bass Island Dolomite and the Mount Simon (Potsdam), the basal sandstone unit. In 1968, well number 3 (PA-8) was completed in the Bass Island Formation from 483-529 m (1586-1737').

It is believed that Mount Simon received very little injection during the operational period, but 4.2 hm^3 (1,097,965,700 gallons) were injected during the life of the system. On April 14, 1968, the casing and tubing of well PA-2 were lifted out of the hole signalling the need for immediate repair and reconditioning of the well. The well returned waste sulphite liquors to the surface for several days at the rate of 8.7 dm^3/s (140 gpm) per day which went directly into Lake Erie. It was necessary to bring a drilling rig and other equipment and materials to the well site to control the backflow. The system was never returned to full use and the three wells of the system were abandoned and plugged in the fall of 1972.

The pressures utilized, 8.6 MPa (1250 psig), were well below critical pressures, being approximately 0.6 of lithostatic. The annulus voids between casing runs were only partially cemented. Corrosion attributed to either galvanic action or escape of the corrosive fluids into the annular spaces caused deterioration of the casing string.

Assessment -

This situation resulted because of poor completion practices. It could have been prevented by all casing strings being cemented following the recommended procedure of a cement bond at least 15 m (50') into the next larger string, setting the tubing on a packer and filling the annulus between tubing and casing with an inhibited fluid.

The sulphite wastes expected upon the surface from the well had a temporary degrading effect upon the environment. The exact radius of influence is not known nor is the length of time over which the effect was present.

Well B

Source and Nature of Waste -

Waste water was steel plant pickling liquor composed of: H_2SO_4 to 10 percent and $FeSO_4$ to 10 percent.

Surface Equipment -

Little has been published regarding surface equipment except that pumping equipment was used capable of injecting the required volume of waste water at a well head pressure of up to 32.1 MPa (4650 psig).

Well Completion and Geology -

The well penetrated the Oriskany Sandstone and later the Onondaga Limestone. The well went into operation in 1961 and operated on a trial basis until 1965. Spent pickle liquors were injected into the Oriskany Sandstone 1641-1660 m (5385-5445') until July 1968. The injection zone was changed to 1398-1413 m (4585-4635'), and included the Genessee, Marcellus Shale, and the Onondaga Limestone. This well was used from April 15, 1965, to June 9, 1972, when it was abandoned and plugged. The operational history shows frequent tubing failures. Another aspect of well operation was concern with respect to the injection pressures applied and the buildup of pressure to maintain the needed rates of injection. Pickle liquors in the amount of 125 247 m³ (33 087 000 gallons) and fresh water in the amount of 293 748 m³ (77 600 090 gallons) were injected At times the wellhead pressure was as high as 19.9 kPa per metre (0.88 psi per foot) of well, which would be approaching hydrofracture levels.

Assessment -

Although the well received about 416 400 m³ (110 000 000 gallons) of injected liquids, it could not be called a completely successful well. The available data indicate that the permeability was not sufficient for a good operation with the volume of waste to be injected. The acid waste injected into the formation contributed greatly to it doing as well as it did, although some formation plugging may have been attributed to the waste. The high injection pressures were due largely to the poor permeability, and the frequent tubing failures were probably due as much to the high injection pressures as to the corrosive liquid being injected through the tubing. An in-depth analysis would undoubtedly show that operating costs for this well were excessive relative to the amount of waste injected. Again directly related to naturally reduced permeability and/or reduced permeability caused by reaction of injected waste and formation minerals. This well appears to have had no deleterious effects upon the environment.

EPA REGION IV

Well A

Source and Nature of the Waste -

One of the world's largest nylon plants on the Escambia River about 21 km (13 mi.) north of Pensacola, Florida. The effluent, an aqueous solution containing nitric acid, inorganic salts, and numerous organic compounds, is injected through two wells into the aquifer between depths of 425-520 m (1400-1700').

Well Completion and Geology -

With reasonable confidence that injection of waste into the lower limestone of the Floridan aquifer could be done safely and economically, the company decided to construct a test well in such a way that it later could be used as an injection well if the hydrogeologic conditions proved to be favorable for injection. A hole was drilled with rotary tools into the upper limestone of the Floridan aquifer. A 24" surface casing was set at 26 m (86') and an 18" steel casing was set at 299 m (982'). All casing was cemented to the surface. After water samples were collected from the upper limestone, the hole was drilled through the Bucatunna Clay Member and into the lower limestone. A 12" steel casing was set at 424 m (1390') and cemented back into the 18" casing. The bottom joint of the 12" casing was type 304 stainless steel. With a reverse-air rotary drilling rig, an open hole was then drilled through the lower limestone and into shale and clay to a total depth of 551 m (1808').

The test well was converted to an injection well by inserting a 6" type 304 stainless steel liner into the 12" steel casing and sealing the annulus at the bottom with a packer. The annular space between the two casings was then filled with a corrosion-inhibitor solution, which is periodically replaced.

Through southern Alabama and northwestern Florida, the sand and gravel aquifer is the major source of fresh water and yields large quantities of water of excellent quality. In the southern part of the area, the Pensacola Clay aquiclude separated into two parts by the Escambia Sand Member, underlies the sand and gravel aquifer; whereas, in the northern part, the Pensacola Clay is absent and the sand and gravel aquifer lies directly on a sequence of sediments known as the Floridan aquifer.

The Floridan aquifer is split into two units by the Bucatunna Clay aquiclude. The unit above the Bucatunna Clay Member (of the Byram Formation) is called the "upper limestone" of the Floridan aquifer; the unit below is called the "lower limestone" of the Floridan aquifer. Water in the upper limestone is probably fresh in the northern half of the Escambia County and in all of Santa Rosa County except the southwestern part.

The Bucatunna Clay aquiclude underlies part of Louisiana, Mississippi, Alabama, and Florida. In Florida, it extends beneath all of Escambia and Santa Rosa Counties. All geologic information indicates that the aquiclude is continuous and relatively thick. It reaches its maximum thickness of about 60 m (200') just north of Pensacola.

The lower limestone of the Floridan aquifer crops out in southern Alabama and dips gradually to the southwest. At Pensacola, it is at a depth of more than 455 m (1500') below mean sea level. Water in this part of the aquifer moves slowly toward the south and, presumably, discharges into the Gulf of Mexico near the edge of the continental shelf, or seeps slowly upward through the confining beds somewhere at sea beneath the continental shelf. Resistivities shown on electric logs indicate the water to be salty, except possibly in the northeastern part of the area.

The only known use of water from the lower limestone in the area is from one well in extreme northeastern Santa Rosa County, more than 48 km (30 mi.) from the company plant. The position of the potentiometric surface is inferred from water-level measurements in several wells tapping the upper limestone, one water-level measurement in the lower limestone obtained from a test well at the injection site, and general geohydrologic information from the area. The assumption has been made that the potentiometric surface of the lower limestone was the same as that of the upper limestone. Inferred chloride concentrations are based on data from a few test holes and numerous geophysical logs of oil-test wells.

Operating History -

The injection rate has increased gradually from about 40 dm^3/s (600 gpm) in 1963 to the present (1971) rate of about 132 dm^3/s (2100 gpm). The wellhead injection pressure in well "A" rose to about 1.6 MPa (225 psi) at an injection rate of about 75 dm^3/s (1200 gpm) prior to the construction of well "B" in 1965. From 1966 through 1968, the injection rate was about 95 dm^3/s (1500 gpm), and injection pressure remained relatively steady at about 1.4 MPa (200 psi). The injection pressure has decreased gradually since 1968, even though the injection rates have increased by about 32 dm^3/s (500 gpm). An explanation for this decrease in injection pressure will be given in a succeeding section of this paper. The total volume of waste injected to November 1971 was about 22.7 hm^3 (6 billion gals.), and the cumulative volume is increasing at a rate of about 3.8 hm^3 (1 billion gals.) per year.

Assessment -

Geochemical and hydraulic effects of this waste-injection system, as of November 1971, had been detected only in the lower limestone of the Floridan aquifer. The acidic waste is neutralized, or at least partially neutralized, by dissolving $CaCO_3$ from the limestone aquifer. Biochemical reactions such as denitrification may further modify the composition of the injected waste. Waste injection has increased formation pressures to an equivalent rise in water levels of more than 60 m (200') within a 1.6 km (1 mile) radius of the injection site; the pressure effects as of late 1971 probably extend outward more than 48 km (30 miles). The injected waste fluid has probably migrated more than 1.6 km (1 mile) in all directions from the injection site. Increased permeability near the injection wells has resulted from dissolution of limestone by the acidic waste and has brought about a decrease in injection pressures, even though injection rates have increased. The possible development of a large cavity in the lower limestone at the base of the Bucatunna Clay is believed to be the greatest threat to the subsurface environment resulting from the injection system. The development of such a cavity would remove support from the base of the Bucatunna Clay and could cause the clay to slough and crumble, eventually allowing waste to leak into the upper limestone of the Floridan aquifer (which contains water at the injection site that is nonpotable according to U. S. Public Health Service (1962) drinking-water standards). If waste does ultimately leak into the upper limestone, the geologic structure is such that leakage into the sand and gravel aquifer is unlikely because of the presence of a second thick confining layer, the Pensacola Clay.

Other Wells

Case histories of other wells in Region IV are discussed in Appendix F, Recent Microbiological Research and in the Chemical Aspects subsection of Section III.

EPA REGION V

Well A

Source and Nature of the Waste -

The waste is the effluent from a chemical plant producing resins and chlordane. The wastewater characteristics are: NaCl = 140 000 ppm, NaOH = 25 000 ppm, NaOCl = 20 000 ppm, pH = 10.5 to 11.5, Sp. gr. = 1.15 (trace organics).

Surface Equipment -

Waste streams are mixed and settled in a 40 000 gallon concrete tank. From this tank transfer pumps pass the waste through filters to pumps which inject the waste into the well.

Well Completion and Geology -

The present disposal well IL-6 is a replacement for IL-1 which failed when a Secureloy section in the casing string was dissolved by the caustic waste. During workover operations, cement and formation caved in on the workover tools and caused the loss of the Devonian disposal zone. As a temporary measure, the Mississippian Salem zone exposed behind the Secureloy windows was used for disposal until the replacement well IL-6 was completed. The IL-6 was completed setting casing on the top of the Devonian Grand Tower Dolomite with the bottom joint being stainless steel. Dowline injection tubing was run on a packer set in the stainless steel casing joint. The annulus between the casing and tubing was filled with inhibiting fluid. An oil pad was placed to fill the annular space between the tailpipe and the holewall below the packer to protect the packer from corrosion.

Assessment -

This well is located on the north side of the Illionis basin. Here the top of the Devonian Dolomite is at a depth of approximately 732 m (2400') and it is about 60 m (200') thick. Since the proper completion was made, the well has taken the waste volume with a minimal buildup in pressure. During 1975 it was receiving about 3.0 dm^3/s (48 gpm) at an average of 558 kPa (81 psi) and was considered a very successful operation. A monitor well was drilled about 1000 feet away to check migration of waste and fluid level (pressure) buildup. No change had been noted in two years of operation through 1973.

The loss of the first well can be attributed directly to the caustic waste fluid contacting the Secureloy sections of the casing. This could have been prevented by setting the injection tubing on a packer and isolating the annulus between the casing and tubing and keeping it filled with inhibited fluid. The use of Secureloy is discouraged in a highly caustic environment as contact with caustic is one method designed to remove them.

Well B

Source and Nature of the Waste -

The source of the waste is pickling liquor from steel plant operations. The nature of the waste is as follows: HCL = 0.5 percent, $FeCl_2$ = 24.0 percent, $H_2Cr_2O_7$ = 1.0 percent.

Surface Equipment -

Holding tanks of 568 m^3 (150 000 gal.) capacity are used before and after filtration through a 5μ diatomaceous earth filter. A centrifugal pump is used for injection.

Well Completion and Geology -

Very little is known about well completion procedures. This well, IL-3, was drilled through the Cambrian (Mount Simon) Sandstone between 947.3-1477 m (3108-4846'), and completed open hole in that interval.

The injection of 248 m^3 (65 600 gals.) of waste per day is being accomplished at an average rate of 8.5 dm^3/s (135 gpm) and an average pressure of 1827 kPa (265 psi).

Continuous monitoring of injection tubing and annular pressure and injection rate is made. Periodic sampling and water quality parameters are measured.

Assessment -

There has been no evidence that the waste has not remained in the Mount Simon Sandstone and the operation overall is considered successful.

Well C

Source and Nature of the Waste -

The waste water is the effluent from a chemical plant and its characteristics are: TDS = 14 000 mg/l, Na_2SO_4 = 6500 mg/l, $(NH_4) SO_4$ = 5005 mg/l, Acidity = 120 mg/l, Sp. gr. = 1.0, pH = 4.6.

Surface Equipment -

Three settling tanks in series receive the waste before it is injected. The wells (2) are monitored for flow and pressure.

Well Completion and Geology -

These wells, IN-1 and IN-2, are apparently completed in the basal Devonian and upper Silurian carbonate rocks. The depth to the top of the injection zone is about 61 m (200') with 12 m (40') of zone open in IN-2 and 121 m (397') in the IN-1.

These wells were developed in 1950 and 1951 before any rules and specifications were set up for this type of project. It is estimated that approximately 18.9 hm^3 (5 000 000 000 gals.) had been injected through mid-1972. Waste is injected at the rate of 2180 m^3 (576 000 gals.) per day at an injection pressure of 241 kPa (35 psig).

Assessment -

This is not regarded [illegible] a prudent operation because of the attitude of th[illegible]ks and the location of the wells in proximity to La[illegible]ichigan. The waste may be escaping into the lake.

Well D

When the State Water Resources Commission objected to the discharge of liquid wastes containing phenols into a river in 1956, the company considered biological treatment of the waste in a large trickling filter. However, after comparing the operating cost with that of subsurface disposal wells, a preliminary geological investigation was made of possible disposal formations. The Sylvania Sandstone at the shallow depth of 147 m (483') appeared suitable for waste disposal. It was estimated that a disposal well and surface equipment for the subsurface disposal system would cost $25,000, which was less than the cost of a trickling filter system.

Source and Nature of Waste -

A hard metallurgical coke for blast furnaces is prepared in coke ovens. Crude benzene is extracted from the coal gas by washing with a light oil which also removes about 95 percent of the naphthalene. Ammonia, removed by scrubbing with water, is reacted with phosphoric acid to make ammonium phosphate. The light hydrocarbons from the gas are used as fuel, and the phenols are mixed with coke quench water to form a waste containing about 0.2 percent phenols. The tar is sold to a local company for manufacturing coal tar products.

Analysis of the water from the Sylvania Sandstone showed that it was not potable. Although some precipitation occurred when the underground water was mixed with the waste, the situation was not serious and could be overcome by acidification of the waste. Therefore, approximately 570 dm^3 (150 gals.) per day of 20 percent hydrochloric acid was added to the waste to reduce the pH below 6.3 and prevent precipitation of salts. After about four months, acidification of waste was discontinued as being unnecessary.

Surface Equipment -

Quench water and the waste stream containing the phenols are collected in a 30 000 gallon sump from which the waste is pumped through leaf-type filters precoated with diatomaceous earth. The waste then is given a final filtration through a cartridge filter before it is pumped into a 3.4 m^3 (900 gals.) clear-waste tank. A liquid level controller governs the operation of a steam-drive, duplex, injection pump having a rated capacity of 6.3 dm^3/s (100 gpm) at 3.1 MPa (450 psig).

Well Completion and Geology -

The disposal well MI-11 is relatively shallow compared with others in use. A 9" hole was drilled to a depth of 147 m (483') and 7" OD casing was run and cemented to the surface. When the cement set, a 6" hole was drilled to a depth of 172 m (563'), forming an open-hole disposal zone 24 m (80') into the Sylvania Sandstone. Waste is injected through 2" tubing set at 149 m (489').

Acidizing and fracturing were necessary during 1957, 1958, and 1960 because of injection pressure increase. The injection pressure was observed to gradually increase from 1.4 MPa (200 psig) following acidizing to the limit of the injection pump 3.1 MPa (450 psig). However, the frequency of acidizing has seemed to decrease after each treatment; the period between the first and second treatment was 1 year; between the second and third 2 years elapsed.

Assessment -

This appears to have been a successful system for nearly 20 years. However, pressure monitoring indicates that fracture threshold pressures are reached and often exceeded. The reason for the increasing pressures should be determined and the environmental impact of the well reevaluated.

EPA REGION VI

Well A

Source and Nature of Waste -

The waste injected into this well, OK-13, is a complex mixture of detergents, paint and varnish removers, hydrocarbon solvents used for oil sludge cleaning, phenols, cresols, and rinse water from electroplating tanks. The only test conducted periodically is pH determination; pH has been found to range from 5.0 to 9.0 in one day.

Surface Equipment -

The waste-collecting sump is a 75.7 m^3 (20 000 gal.) tank buried 4.6 m (15') underground. All liquid waste from the maintenance area flows by gravity through drain lines into this tank. Two lobe pumps, each rated at 12.6 m^3/s (200 gpm) are used to pump the waste from the underground sump to the clarifier on the surface. Originally, two duplex stainless steel centrifugal pumps were used, but they were replaced because excessive bearing and shaft wear caused frequent shutdown. However, the lobe pumps have not given trouble-free operation. In January 1962, an accident in the maintenance area caused a surge of a caustic cleaning solvent that was sufficiently high to dissolve the buna-N rubber sleeves that cover the pump lobes, causing a maintenance shutdown.

The clarifier is a 113.6 m^3 (30 000 gal.) automatic skimmer. Oil that floats to the top of the aqueous waste is skimmed and drained into a tank by gravity flow. A scraper at the bottom of the tank removes accumulated sludge. The insoluble oil and sludge are hauled away. Although the clarifier is rated for 42.3 dm^3/s (670 gpm) with a detention time of 47 minutes, it did not prove adequate for this system because oil and sludge appear in the equalizer basin, indicating that a longer detention time is necessary to treat this waste.

From the clarifier, the waste flows by gravity into a 757 m^3 (200 000 gal.) equalizer basin. This tank is equipped with a manually operated skimmer and bottom rake to remove the oil and sludge that overflow from the clarifier. The sludge is skimmed twice a week. The equalizer allows time for mixing the many components of the waste and thus provides a more uniform waste for disposal. It also serves as a detention reservoir for the injection pumps. A float switch is provided to shut off the injection pumps at a minimum liquid level. The equalizer basin is constructed with a cement bottom and carbon steel sides. A leak-proof seal between the cement bottom and steel sides is difficult to maintain.

The injection pumps are set in a basement approximately 3 m (10') below the surface to receive waste by gravity feed from the equalizer basin. Two triplex, piston-type, positive displacement pumps rated for 9.5 dm^3/s (150 gpm) at 4.1 MPa (600 psig) are driven by 44.8 kW (60 hp) electric motors. The pumps are equipped with 3" ceramic pistons and aluminum-bronze fluid ends. Positive displacement pumps were selected because of their characteristic of delivering a constant volume under varying pressures. Pressure fluctuations and eventual plugging of the formation were anticipated in the original design; however, four months after startup the operating pressure leveled out at 1.9 MPa (280 psig) and has not changed except for a few fluctuations of ± 2.8 kPa (40 psig).

Well Completion and Geology -

The top of the Arbuckle Group (a sequence of carbonate rocks) occurs in this area at 527 m (1 729') below the surface and extends to the top of the granite at 925 m (3 036'). Seven inch OD casing was cemented to a depth of 551 m (1 807') to ensure a good seal into the top of the Arbuckle Group. A string of 2-1/2" OD tubing was run to a point near the bottom of the disposal well. Injection began in January 1962.

A monitoring well drilled to the deepest layer of fresh water at 55 m (180') is sampled weekly. There has been no indication of contamination in the fresh water monitor well.

Assessment -

This has been a very successful injection system. It has had only minor operational and maintenance problems. Data indicates that after 15 years of continuous service, a long useful operational life still remains.

Well B

Source and Nature of the Waste -

The waste effluent arises from the operation of an oil refinery, gasoline plant, and petrochemical plant, all located at the plant complex in the Texas Panhandle. The oil refinery and gasoline plant have been in operation since about 1930. The petrochemical plant, only recently constructed, produces sulfuric acid, ammonia, and products manufactured from petroleum. Cooling-tower blowdown, process vessel drainage, and boiler blowdown are the primary constituents of the waste fluids. A typical analysis of some of the principal constituents follows:

Chemical	Concentration ppm
Total hardness ($CaCO_3$ + $MgCO_3$)	716
Calcium hardness ($CaCO_3$)	410
Magnesium hardness ($MgCO_3$)	306
Chloride (Cl)	760
Silica (SiO_2)	90
Sulphate (SO_4)	1440

Other trace constituents not indicated in the analysis include nitrogen compounds (principally ammonia), chromates, and various hydrocarbon derivatives. The waste has a pH of 8. Total waste-water production at the plant is about 69 dm^3/s (1100 gpm).

Surface Equipment -

A large part of the effluent created by the complex is routed directly to a large concrete settling basin which was constructed in 1964. Effluent containing oils and high in suspended solids is run through a clarifier before being combined with cooling-tower and boiler-water effluent in the concrete settling basin. The final waste is pumped to the two injection wells at the plant. The waste is clarified of suspended solids, and the pH is controlled between 7.5 and 8.5 to protect the treating and disposal equipment.

Several large unlined earthen pits were used for discharge of waste water at the plant prior to 1958; however, only one large pit 244 by 305 by 15 m (800x1000x50') remains in use at the plant. Some waste was discharged into a creek on the plant property.

Geology -

The plant is located on an undetermined thickness of predominantly windblown, unconsolidated silt and sand deposits of Recent age. These deposits overlie clay, silt, sand, and gravel beds of the Ogallala Formation of Pliocene age, which is on the order of 137-152 m (450-500') thick in the plant area.

The Ogallala is unconformably underlain by a thin sequence of red and green shale, clay, and sandstone of the Dockum Group of Triassic age. Unconformably underlying the Triassic beds are rocks of Permian age, principally red shale in the upper part of the section. The Blaine Gypsum, a massive marker zone of predominantly gypsum and anhydrite, occurs at depths from 262-334 m (860-1095') in the area and directly overlies the Glorieta sand, which is the waste-injection zone. The Ogallala Formation supplies all fresh water used for irrigation, municipal, industrial, domestic, and stock-watering purposes in the area. All industrial water utilized at the plant is obtained from wells.

The Glorieta sand is a loosely to well consolidated, fine-to-medium grained, well rounded, gypsum- and halite-bearing quartz sandstone which extends over large parts of the northern High Plains. Except in the eastern part of the Texas Panhandle, the Glorieta generally has good porosity, relatively high permeability, and comparatively low reservoir pressure. Owing to its favorable reservoir characteristics and its relatively shallow depth, most of the oil-field-brine-disposal wells and other industrial waste-injection wells in the northern High Plains use the Glorieta for waste-storage purposes.

Although no precise reservoir data are available for the Glorieta in the plant area, the history of operation of the two existing injection wells and the fact that the fluid level in the proposed well approximately 783 m^3 (27 650 cubic feet) of waste will be injected each year. Based on a radial dispersion and complete displacement of the connate water, the effluent would migrate 43 m (140') from the well in 20 years. However, as discussed above, the waste should migrate in an easterly direction from the well.

Numerous oil and gas test wells were drilled on and adjacent to the salt dome. These wells contained insufficient surface casing and cement plugs to adequately protect the fresh water resources. The nearest abandoned well was 76 m (250') north of the disposal well. This well was reentered and properly plugged.

Other producing and abandoned wells are located 91 m (300') or more from the disposal well. Calculations of the pressure increase on the disposal formation after 20 years of injecting should cause a pressure increase of 48 kPa (7 psi) or less at a distance of 30 m (100') from the well and considerably less at 91 m (300'). This increase is not great enough to overcome the weight of the mud columns in the abandoned wells and permit upward flow of salt water in the wellbore.

Well Completion and Operation -

The injection well, TX-20, was originally completed in March 1959, and operated as an LPG storage well in the Clearfork Salt section occurring in the approximate depth interval from 457-494 m (1500-1620'). It was recompleted for waste-disposal purposes. A 13-3/8 inch surface casing had been set at 184m (603') and cemented with 500 sacks of cement. A string of 9-5/8 inch, 32.3 lb, H-40 casing was set at 473 m (1551') and cemented with 11.3 m (400 cubic feet) of cement containing 4536 kg (10 000 lb.) of Gilsonite.

The original string of 7 inch, 20 lb., J-55 casing was suspended from the wellhead to a depth of 494 m (1620'). During recompletion, an attempt was made to pull this casing; however, the bottom part was stuck, and it parted at 434 m (1425') leaving 56 m (185') of casing in the hole. The inside of the 9-5/8 inch casing was cleaned with a casing scraper to a depth of 427 m (1400'). A cement density log and correlation collar log run from surface to 427 m (1400') showed cement behind the 9-5/8 inch casing from 422 m to at least 201 m (1383 to at least 660'). The cement could be higher than 201 m (660'), but the water level in the well was at 201 m (660') and the logging tool will not indicate cement bonding out of liquid. A 2 foot Baker cast iron plug was set in the 9-5/8 inch casing from 396.2-396.8 m (1300-1302').

The 9-5/8 inch casing was perforated opposite the Glorieta sand with one hole per foot from 340-377 m (1116-1236'). In April 1965, the perforations were treated with 3.8 m^3 (1000 gals.) of 15 percent mud acid. The acid was displaced with 61 m^3 (385 barrels) of water at an injection rate of 58 dm^3/s (924 gpm) and a pumping pressure of 2.1 MPa (300 psig). The pump was stopped and pressure dropped to a vacuum. An additional 16 m^3 (100 barrels) of water was injected at a rate of 32 dm^3/s (504 gpm) with no pressure. A string of 7 inch 20 lb, J-55 casing equipped with a packer having both rubber and lead seals was set at 332 m (1089').

Assessment -

The operation can be considered successful. Studies of possible contamination of the Ogallala Aquifer by injection into the Glorieta Formation were conducted in 1970 by the FWQA in Texas County, Oklahoma (Panhandle area). It was concluded that no natural possibility existed for Glorieta water to migrate into the Ogallala Aquifer except in some limited areas of the county. It was recommended, however, that the quality of natural Glorieta water be determined to ascertain any changes caused by injection. These analyses would be used to evaluate potential uses and pollutional hazards of the Glorieta waters.

Well C'

Source and Nature of the Waste -

Diversification of the Gulf Coast chemical plant in 1970 resulted in production of an aqueous waste that could not be adequately treated, for surface discharge, by the existing waste treatment facilities of the plant. Therefore, underground injection of the waste was selected as the best alternative. The waste consists principally of sulfuric acid, ammonium sulfate, and some organics. In addition, a trace amount of cyanide is present. The makeup of the waste stream is shown in the following analysis.

Constituent	ppm
Sulfuric acid	17 000
Ammonium sulfate	44 000
Hydrogen cyanide	10
Glycolonitrile	5 000
Iminodiacetronitrile	3 000
Nitritotriacetonitrile	2 000
Methanol	1 000
Methyl formate	500
Formaldehyde	500
Glycolic acid	4 000
Formic acid	5 000
Density, g/ml	1.0
Viscosity, cp	0.50
pH	1.5

Surface Equipment -

The corrosive aqueous waste flows through a vinyl ester fiberglass pipe to a 117 m^3 (31 000 gals.) storage tank. Two 186 kW (250 hp) pumps move it through two cartridge-type filters and into the injection well. Each pump is equipped with an automatic valve that releases the waste effluent to a bypass line which is connected to an emergency holding pond. This pond is used for storage of effluent when the well becomes inoperative. The emergency holding pond is 151 m (500') long by 61 m (200') wide with an average depth of 3 m (10'). It is lined with bentonite, and the interior surface is covered with a plastic liner.

Geology -

The plant is located on the Gulf Coast of Texas approximately in the center of the upper Texas portion of the Gulf Coast Geosyncline. Typically, this region is characterized by and can be described as a southeast dipping homocline interrupted by salt movements, both of the piercement and deep seated types, and faulting. The major faults generally are not associated with the salt movements but are regional down to the coast faults that are contemporaneous with deposition; that is, the downthrown blocks generally have a much thicker section than comparable upthrown equivalent.

In the locale there are several prominent geological features. The first of these is the strong structural ridging that is in evidence on all the structural horizons presented. A similar feature occurs immediately to the east resulting in a synclinal closure between these two features. The net effect of this structural configuration is that any fluid movement in a downdip direction would be toward these synclinal areas which are quite extensive in the lateral east-west direction.

The plant is on an outcrop of the Beaumont Clay of the Pleistocene Series. The Beaumont consists of alternating sand and clay beds. The Alta Loma Sandstone, a major aquifer in the area, is the basal member.

Underlying the Beaumont in descending order are the Lissie Formation of the Pleistocene Series, the Willis Sandstone and the Goliad Sandstone of the Pleistocene Series, and the Lagarto Clay of the Miocene Series. All of these formations are composed of leticular beds of sandstone, gravel, silt, and clay. They have a combined thickness, including the Beaumont, of approximately 1341 m (4400').

The massive clay section of the Anahuac Stage underlies the Lagarto Clay. The bed is wedge shaped and pinches out within a few miles to the north. It has a thickness in excess of 213 m (700') in the subject area.

The Frio group that underlies the Anahuac Stage consists of massive sandstones interbedded with thick to thin beds of clay. The Frio Group has a thickness in excess of 610 m (2000') in the area of the plant site.

Groundwater, from fresh to potentially beneficial quality, occurs to a depth of 793 m (2600') in the area. The operating company has five water wells on the property that furnish water for the plant operation.

Well Completion and Operation -

The disposal well is drilled to a total depth of 2134 m (7000') and completed with 13-3/8 inch, 51 lb., K-55 surface casing set at 823 m (2700') and 9-5/8 inch, 36 lb., K-55 casing set at 1945 m (6380'). Both casing strings are cemented from total depth to the surface.

The wellbore was underreamed from 1945-2134 m (6380-7000') to 380 mm (15 inches) or larger. A 6-5/8 inch slotted fibercast liner was set in the interval. The annulus between the liner and reamed hole was gravel packed.

The injection tubing is 5-1/2 inch, 14 and 15.5 lb, K-55 internally coated casing. The tubing contains a sealing assembly that is set in a receptacle at the bottom of the casing.

The injection zone consists of massive sand beds of the Frio Group in the interval from 1945-2134 m (6380-7000'). Net sand thickness is about 145 m (475'). The sand has a porosity of 30 percent and permeabilities ranging up to 1.0 darcy with an average of about 450 millidarcys. Approximately 1128 m (3700') of sand and clay beds lay between the base of fresh water and the top of the injection interval. These strata constitute an effective barrier to vertical migration of the waste effluent.

Assessment -

This can be considered a successfully operating system. Based upon available data, the injection is having no detrimental effect upon the environment.

EPA REGION VIII

Well A

Source and Nature of the Waste -

A waste brine and waste which had a pH 8 and contained ammonia, nitrates, chlorides, chlorates, chlorinated hydrocarbons, and organic phosphorous compounds from the manufacture of the insecticides chlordane, aldrin, and dieldrin originally were disposed of by seepage and evaporation from large reservoirs; however, a more reliable method of waste disposal was desired. Subsurface disposal offered the best solution to the problem, and drilling was started on a disposal well, CO-1, in March 1961. Routine injection of the accumulated waste began in March 1962.

Surface Equipment -

The waste effluent streams of approximately 22-28 m^3/s (350-450 gpm) were discharged into a 36 420 m^2 (9 acres) asphalt-lined waste reservoir. Aerating towers at the reservoir aided in reducing the water content of the waste effluent. Two single-stage centrifugal pumps moved the waste from the reservoir about 61 m (200') to the injection treating plant.

The waste first flowed into a 1115 m^3 (12 000 gal.) concrete sedimentation tank from which it flowed by gravity into a 2787 m^3 (30 000 gal.) clarifier equipped with a skimmer and sludge rake. The clarifier was originally installed to aid in preinjection treatment of the waste with flocculating agents; however, because the floc that formed would neither settle nor float this process was abandoned. The clarifier was then used as an extra detention tank.

The waste was pumped from the detention tank to one of two leaf filters, each of which had filter surface area of 42 m^2 (450 sq. ft.). Chemically treated diatomaceous earth was used along with asbestos for precoating the filters. Engineering consultants recommended filtration to less than 20 ppm of suspended material of 0.5 μ particle size. This is both expensive and difficult to accomplish; however, it was essential for removal of a high percentage of microorganisms identified as *Paracloan aeroginoids* and *Bacillus subtilis* which grew in colonies of colorless slime in the waste reservoir and presented a problem of removal before injection. A bactericide injected after filtration accomplished complete bacterial control.

The company installed the necessary equipment to bypass the reservoir and to inject the waste directly, thus eliminating the need for filtration and bactericides, inasmuch as the process waste streams were sterile when they left the plant. Accumulated waste in the reservoir was disposed of by concentration through solar evaporation and by intermittent subsurface injection.

In addition to the bactericide, sodium sulfite was added to the waste after filtration to act as an oxygen scavenger to protect the well from corrosion by dissolved oxygen acquired by exposure to the atmosphere.

After filtration and treatment, the waste was pumped into a 4645 m^3 (50 000 gal.) clear tank equipped with a float switch that activated one or more, as required, of the four injection pumps.

Four reciprocating, positive displacement pumps discharged into a common fluid manifold with a pulsation dampener as a precaution against water hammer. Each pump was powered by a 96.9 kW (130 hp) electric motor and was rated at 6 dm^3/s (95 gpm) and 13.9 MPa (2000 psi). A pressure relief valve was set at 10.3 MPa (1500 psi). Normal operating wellhead pressure fluctuates from 3.4 MPa (500 psi) at 13 dm^3/s to 5.7 MPa (820 psi) at 25 dm^3/s (400 gpm).

Well Completion and Geology

The disposal well was drilled to a total depth of 3671 m (12 045') and cased with 5-1/2 inch casing cemented at 3650 m (11 975') leaving 21 m (70') of open hole in the Precambrian gneiss exposed for injection.

A string of 13-3/8 inch OD casing was set at 610 m (2000') in a 24 inch hole and cemented to the surface to protect fresh water aquifers above 451 m (1480'). Near the base of the Fountain Formation, 3453 m (11 330'), drilling became difficult because of prolonged periods of lost circulation and, therefore, a string of 8-5/8 inch OD casing was set and cemented at 2737 m (8980'). Drilling then proceeded to a Precambrian gneiss that was cored and found to be highly fractured. This fractured zone offered the best potential for a disposal reservoir; therefore, a 5-1/2 inch OD casing was set and cemented in place from the bottom of the 8-5/8 inch OD casing to the top of the Precambrian gneiss at a total depth of 3650 m (11 975').

From March, 1962 until February, 1966, a volume of 625 593 m^3 (165 million gal.) was injected at a maximum rate of 32 dm^3/s (514 gpm) and 7.5 MPa (1100 psi) [average rate 13 dm^3/s (200 gpm) and 3.4 MPa (500 psi)]. The seventh week after injection began on April 24, 1962, an earthquake of magnitude 1.5 was recorded. From April 24, 1962, through August, 1967, 1514 earthquakes were recorded with magnitudes ranging from 0.5 to 5.3; all relatively shallow in origin and from an area about midway between central Denver and the Arsenal well.

Earthquake frequency correlated closely with injection schedules. This helped substantiate the theory that the injected fluids acted as a lubricant on the fracture and joint surfaces, and that this factor plus the pressure applied in injecting the fluid upset the equilibrium of the rocks in the area and caused movement along the fracture surfaces, and earthquakes. After use of the well was discontinued, the seismic conditions approached those prior to injection.

Assessment -

The discontinuance of the use of this well was advisable because of its effect upon the environment. The situation may have been predictable by in-depth feasibility studies prior to drilling, but this is only conjecture. Also, the earthquakes triggered by the fluids injected into this well may have been instrumental in relieving enough stress to prevent a major earthquake in the area.

SECTION XI

APPENDIX E

REFERENCE CITED

Donaldson, E. C., et al, Subsurface Waste Injection in the United States, U. S. Bur. Mines Inform. Circ. 8636, 72 pp, 1974.

SECTION XI

APPENDIX F - RECENT MICROBIOLOGICAL RESEARCH INCLUDING WILMINGTON AND BELLE GLADE CASE STUDIES

BACTERIAL PHYSIOLOGY

Bacteria can survive and remain viable over a wide range of environmental conditions. Some of the environmental limits were described by Ehrlich[1] after Brock,[2] and have been summarized in Table 21. A distinction exists between the ability to survive and the ability to grow well: e.g., optimal temperatures for growth of nearly all microorganisms are near the upper, maximal limits of their range. The optimal and limiting factors are, in general, the optimal and limiting factors of their enzymes according to Frobisher.[3]

Table 21. ENVIRONMENTAL LIMITS FOR GROWTH AND REPRODUCTION OF SELECTED MICROORGANISMS[1]

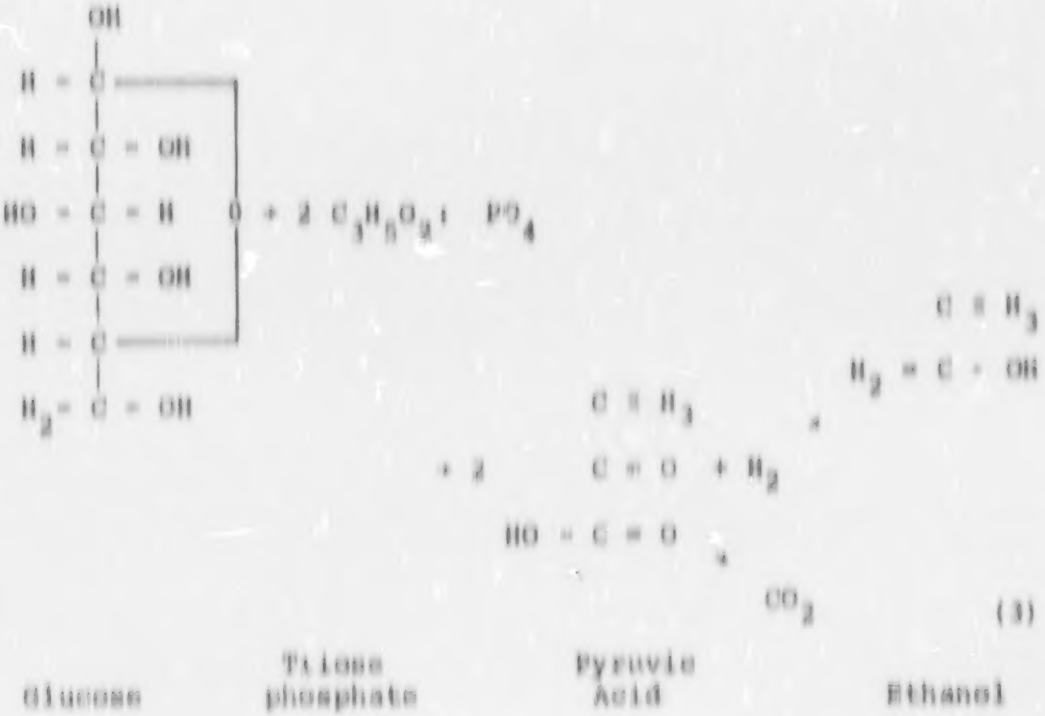
Factor	Lower Limit	Upper Limit
Temperature	-12°C (fungi, bacteria)	104°C (sulfate-reducing bacteria at 1,000 atm)
Oxidation-reduction	-350 to -450 mv at pH 8 to 9.5 (sulfate-reducing bacteria)	+850 mv at pH 8 (iron bacteria)
pH	0 (*Acontium velatur*, *Thiobacillus thiooxidans*)	13(?) (*Plectonema nostocorum*)
Hydrostatic pressure	Practically 0	1,400 atm (deep-sea bacteria)
Salinity	Double distilled water (heterotrophic bacteria)	Saturated brines (*Dunaliella*, halophilic bacteria)

Metabolic activities of bacteria occur in one of three modes with many bacteria having the ability to grow in two of the three modes, i.e., facultative bacteria. The three modes are photosynthesis, aerobic respiration, and anaerobic fermentation and respiration. Bacterial photosynthesis requires light absorption at 7400 Å (orange-yellow range) for the Chlorobacteraceae and 8000-9000 Å (infra-red range) for the brown, red, and purple pigmented species according to Frobisher.[1] Photosynthesis does not occur in the permanent darkness of underground formations and could only be of interest in surface treatment or holding facilities exposed to light. Respiration (aerobic) is an energy-yielding process in which organic compounds or reduced inorganic compounds serve as electron donors and molecular oxygen serves as the acceptor according to Ehrlich.[1] As in photosynthesis, respiration does not occur in injection formations, since groundwater is generally lacking in dissolved oxygen. However, aerobic respiration can be of considerable importance in the pre-injection system.

Anaerobic bacteria have developed metabolic processes which occur in the absence of oxygen. These microorganisms may be obligate anaerobes (limited by contact with molecular oxygen) or facultatives (able to grow either aerobically or anaerobically). Energy production by anaerobes can proceed in two general ways: fermentation, or anaerobic respiration.

Fermentation (intramolecular respiration) is the commonest type of anaerobic metabolism. The final hydrogen acceptor is derived from the nutrient substrate itself. Part of the nutrient molecule is oxidized, while part is reduced. The fermentation of glucose is shown as an example in Equation 3.

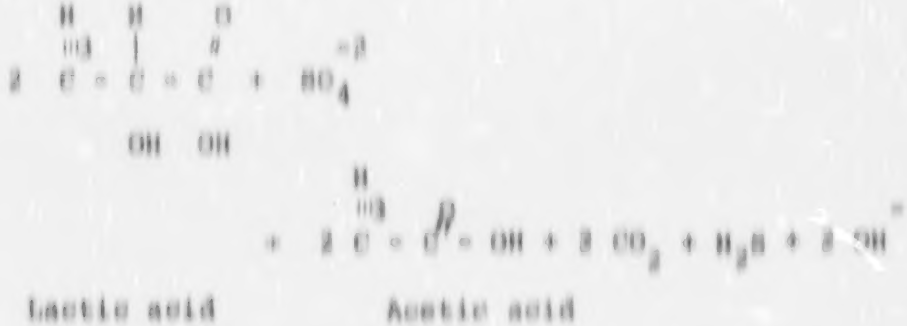
The six carbon sugar is split by enzymes into two 3-carbon sugars and phosphorylated. Through a series of chemical transformations these 3-carbon sugars are changed to pyruvic acid. Part of the pyruvic acid is eventually changed to alcohol and carbon dioxide. In the process of dissimilation of the glucose, hydrogen has been removed from parts of the molecule (oxidation) and shifted to other parts of the same molecule (reduction). For further information concerning


OH
H - C
H - C - OH
HO - C - H
H - C - OH
H - C
H_2 - C - OH
O + 2 $C_3H_5O_3$: PO_4
+ 2
C ≡ H_3
C = O + H_2
HO - C = O
CO_2
C ≡ H_3
H_2 = C - OH
Glucose
Triose phosphate
Pyruvic Acid
Ethanol

(3)

the varying metabolic pathways and enzymatic actions, see the Meyerhof-Emden scheme for dissimilation of glucose to pyruvic acid.

The second method is called anaerobic respiration (intermolecular respiration) in which the final hydrogen acceptor is some extraneous substance like $NaNO_3$ or some organic compound. Hydrogen is transferred from one molecule to another. The essential chemistry involved is illustrated by the reaction between lactic acid and sulfate in Equation 4.


Lactic acid
Acetic acid

$$2\ \overset{H_3}{C}-\underset{OH}{\overset{H}{C}}-\underset{OH}{\overset{O}{\overset{\|}{C}}} + SO_4^{-2}$$

$$+\ 2\ \overset{H_3}{C}-\overset{O}{\overset{\|}{C}}-OH + 2\ CO_2 + H_2S + 2\ OH^{-} \qquad (4)$$

Other organic compounds such as ethanol, butanol, glycols, amino acids, and glucose can also be utilized by bacteria as hydrogen acceptors. Carbon dioxide can be reduced to methane and nitrate to nitrite and are further examples of anaerobic respiration.

The variety of organic compounds which can be dissimilated by bacteria is very large. Humic materials are attacked very slowly. Some compounds are virtually immune to microbial dissimilation: chlorinated hydrocarbon pesticides, certain detergents, and polyolefin plastics.

Bacteria require certain inorganic elements for protoplasmic synthesis. These elements include traces of K, Mg, Fe, Mn, Zn, Cu, Co, and Mb, which are usually available in the groundwater. Other elements are required in larger quantities: N, P, and S, which may be limiting factors for growth. See Table 22 for a list of general nutritional requirements.[6]

Table 22. A LIST OF GENERAL NUTRITIONAL REQUIREMENTS[6]

1. Energy source	Organic compounds Inorganic compounds
2. Electron acceptor	Oxygen Organic compounds Nitrate (NO_3-), nitrite (NO_2-), nitrous oxide (N_2O), sulfate ($SO_4 2-$), carbon dioxide (CO_2)
3. Minerals	Nitrogen, phosphorous, potassium, magnesium, sulfur, iron, calcium, manganese, zinc, copper, cobalt, molybdenum
4. Growth factor	
a. Amino acids	Alonine, aspartic acid, glutamic acid, etc.
b. Vitamins	Thiamin, biotin, pyridoxine, riboflavin, nicotinic acid, pantothenic acid, paminobenzoic acid, folic acid, thiotic acid, B_{12}, etc.
c. Others	Purine bases, pyrimidine bases, choline, inositol, peptides, etc.

RECENT RESEARCH METHODS

Signor[5] has analysed in vitro data to relate the physical, biological, and geochemical effects of the porous media flow system. The objective was to obtain data that could be transferred to field situations as an aid in developing more effective and economical artificial recharge systems. This data may well be useful in application to research on the microbial aspects of deep-well waste injection.

REVIEW OF LITERATURE

1) Sakthivadivel and Irmay[6] review of filtration theory and experiments, concluded that the critical parameter in clogging of a porous medium is the ratio of the diameter of the matrix opening to that of the fines. Between pore particle-diameter ratios of 5-14 clogging or nonclogging depends on porosity of the matrix.

2) Heertjes and Lerk[7] found that when the suspension to be filtered is a stable colloid and the filter material has pore sizes several orders of magnitude larger than the colloid particle diameter, suspension removal is by electrokinetic sorption on the filter medium.

3) Herzig, et al,[8] concluded that for suspended particles > 30 µm volume phenomena prevail and for < 1 µm particles surface effects prevail. Particles between these sizes show both volume and surface effects in the same order of magnitude.

4) Edwards and Monke[9] hypothesised that bacteria may provide an electrical link between negatively charged silica and bentonite clay particles.

5) Rahman[10] in a radial-sector well model of uniform porosity observed that 10-20 percent of a bentonite-kaolinite suspension remained in the model aquifer after 8 hours of inflow. A sediment concentration of 500 mg/l reduced the inflow rate by 43-47 percent in that length of time.

6) Curry and Beasley[11] concluded from laboratory column tests that mechanical filtering is the main process

by which bentonite particles are removed from suspension by carborundum medium.

7) Curry, et al,[12] found that there appeared to be mechanical seiving at the inflow surface in porous media and diffusion and gravitational settling below the surface.

8) Vecchioli,[13] Ehrlich, et al,[14,15] added chlorine to injection streams to deal with the problem of bacterial clogging.

9) Rebhun and Schwarz[16] suggested that small volume pumping be used to redevelop wells and remove organic material from near the well bore.

10) Nevo and Mitchell[17] found that the formation of microbial polysaccharides in sandy bottoms of spreading basins under anaerobic conditions promoted clogging.

11) Wood and Bassett[18] found that major chemical changes in infiltered water sampled below a spreading basin correlated directly with changes in infiltration rates and were a response to bacterial actions as well as being useful to distinguish loss of infiltration rate caused by bacterial activity from that caused by sediments.

12) Sniegocki[19] cites air entrainment, suspended particles, and microorganisms as the principal cause of clogging in injection wells.

Signor[9] states that the difficulty encountered in transferring existing research results to the field situation lies in part in the complexity of the natural systems. Lithologic units are extremely variable porous media, and injected wastes are subject to wide variation in physical and chemical parameters.

RESEARCH FACILITIES

The requirements of a laboratory designed for transmissivities studies of porous media under conditions of injection well operations according to Signor[5] are:

1) A source of relatively large quantities of injection fluid which can be altered to any desired quality in regard to suspended materials and dissolved materials.

2) A flow system which permits complete flow measurement and control of flow rates and pressures, and which can be operated under constant conditions of pressure and flow.

3) Capability for evaluating the physical, chemical, and biological characteristics of the clogging process.

DESIGN OF A MODEL

In order to produce a model for studying flow through porous media, Signor[5] used a test column with axially and radially homogeneous media packing (Figure 191). This packing was accomplished by using a full tremie pipe with an acrylic disk with radial cleats on the end of the tremie tube. This arrangement allows a homogeneous pack and is repeatable (Figure 192).

In flow studies piezometer taps provide true pressure measurements if placed with inlets in the interior of the porous matrix. An input system equipped with a mixing pump assures solids in uniform suspension as the fluid enters the inflow face of the mixture. Delivery lines are no more than 10 mm inside diameter so that settling in the lines cannot occur.

The characteristics of clay suspension during flow is the most difficult parameter. Concentrations were determined directly by filtering the sample and weighing the retained particulate matter with an analytical balance. Physical parameters are listed in Table 23. Signor[5] has extensive tests in progress for investigating a broad range of parameters affecting waste injection.

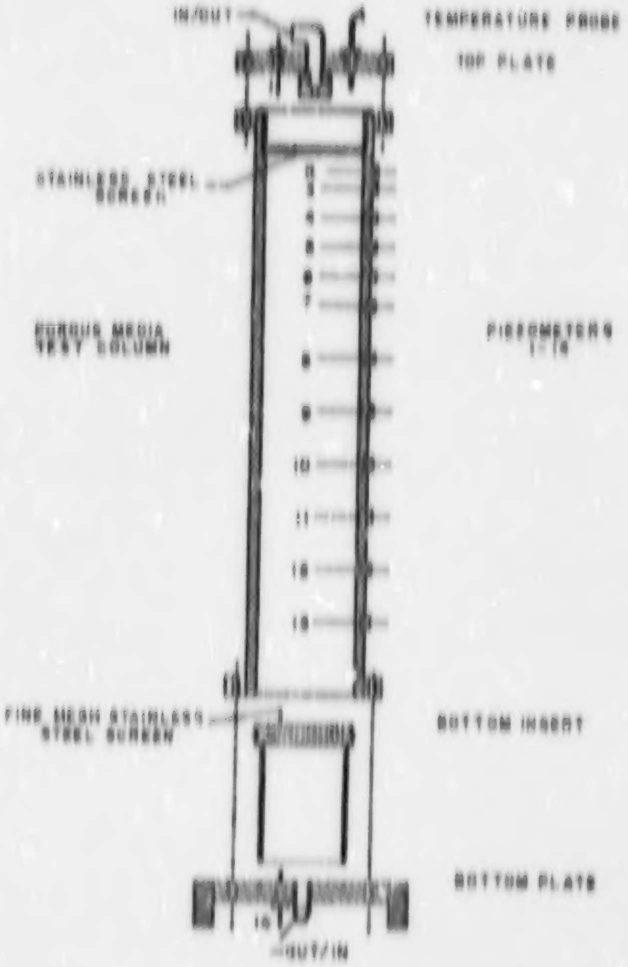

IN/OUT
TEMPERATURE PROBE
TOP PLATE
STAINLESS STEEL SCREEN
2
3
4
5
6
7
POROUS MEDIA TEST COLUMN
PIEZOMETERS 1-16
8
9
10
11
12
13
FINE MESH STAINLESS STEEL SCREEN
BOTTOM INSERT
6 O-RINGS
BOTTOM PLATE
14
OUT/IN

Figure 191. Construction and assembly of porous-medium test column.

Figure 192. Rotating tremie and vibration system for packing test column with sand.

Table 23. PHYSICAL PARAMETERS OF POROUS-MEDIA FLOW[a]

Matrix Parameter	Significance
Porosity	Indicates voids, space available for retention of clogging material.
Particle size in medium for which 10 percent is smaller than that size	Termed the effective size for filter sands.
Particle size in medium for which 60 percent is smaller than that size.	The ratio of the 60 percent size to the 10 percent size is an indicator of the uniformity.

(Table 23. continued)

Bulk density of medium	For a given material, indicates the solidity of packing and propensity for material movement under stress.
Specific surface area of medium	Relates to surface-active phenomena and adsorption rate.
Grain shapes in medium	Affects shape of pores and thus fluid-flow patterns.
Surface roughness of medium grains	Affects retention of suspension on the particle surface.
Intrinsic permeability	Integration of porous-media characteristics.
Pore-diameter size and size distribution	Propensity for entrapment or filtration of suspension.
Surface charge of grains	Attraction to suspension particles.
Fluid	Significance
Viscosity	Shear forces and fluid resistance to flow.
Density	Fluid characteristics.
Velocity of flow	Hydrodynamic forces on the medium and suspension.
Pressure	Driving force moving the liquid and suspension into and through the medium.

(Table 23. continued)

Suspended Particles	Significance
Concentration (inflow, within medium, outflow)	Material available for inflow, retention, and through-flow.
Size	Ability to pass through pore openings.
Shape	Effect on retention or through-flow due to orientation.
Electric charge	Attraction or repulsion to medium or intermediate materials.

PRELIMINARY TESTS AND RESULTS

Signor's[3] initial studies were directed toward physical measurements of the plugging caused by suspended solids in injection water. Preliminary results showed rapid reduction in permeability due to suspended solids.

The problem of determining actual clogging configurations was approached by using a scanning electron microscope (Figure 193). This technique showed the accumulation of suspended solids on the sand grains and collections at the medium-grain contact points. The collection of suspended particles does not appear to occupy any significant part of the pore space or interstital area in the medium, yet the permeability of the medium was reduced by about 80 percent in the test.

In a test for clogging by bacterial growth, a vortex-shaped deposit of organic material was formed (Figure 193). Bacterial growth on a stainless steel screen caused deterioration of the screen in the form of circular pits approximately 1 mm in diameter (Figure 194). Seven such pits appeared on a screen 13 cm in diameter during a period of 10 days. Dispersive x-ray analysis of the organic material compared to an analysis of screen filings showed that the organic material was composed primarily of iron or contained iron, the same material as the screen.[18]

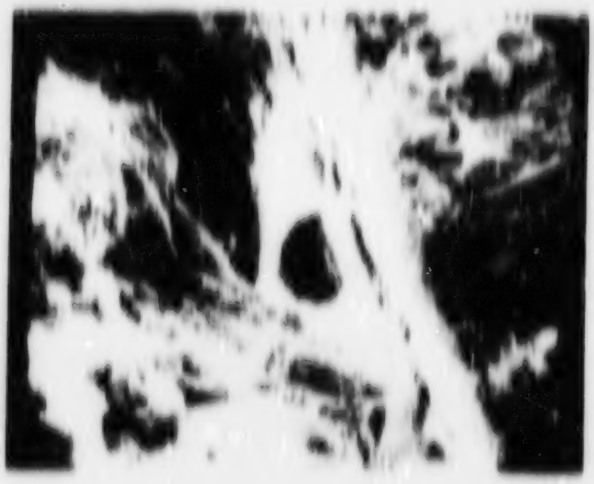


Figure 193. Scanning electron micrograph of vortex-shaped organic deposit in interstitial opening in porous medium.

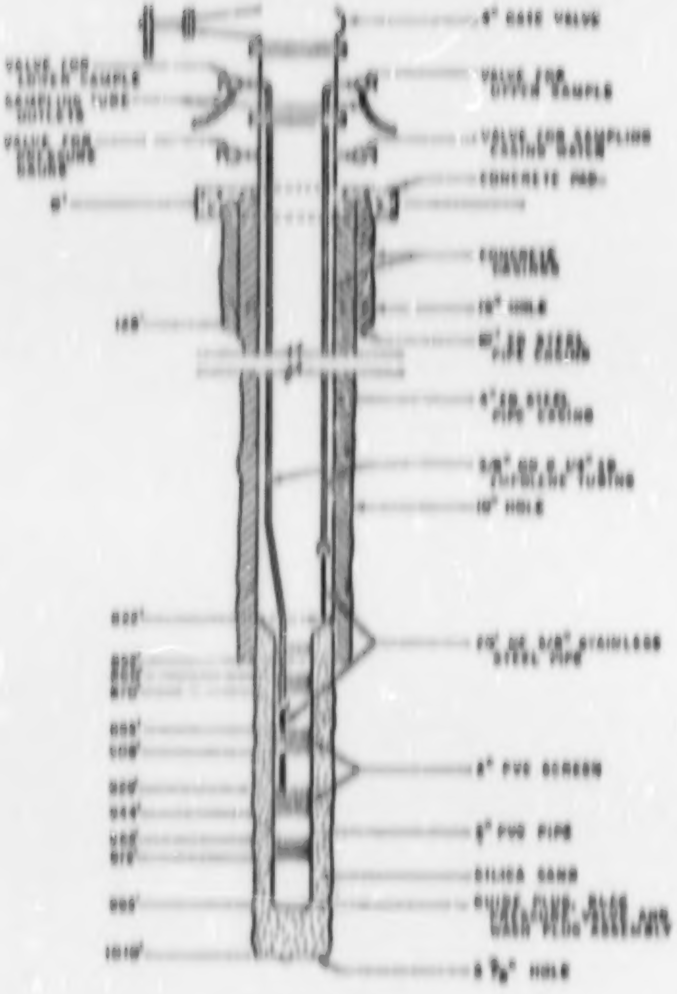
Figure 194. Pits in stainless steel screen due to bacterial growth during 10-day period.

In collecting samples from monitor wells for biogeochemical analyses in the Wilmington, N. C., studies, (mentioned elsewhere in this report) Leenheer and Malcolm[26,27] and DiTommaso and Elkan[22] utilized rather unique methods necessitated by the design of the monitor wells and the artesian head of the injection zone salaquifer. A representative monitor well is shown in Figure 195. The natural artesian head allowed the collecting of samples by simply opening the outlet valve at the top of the sampling tubing.

The small diameter, 6.35 mm (0.25 in) of the sampling tubing enables collection of a relatively uncontaminated sample after only a thirty-minute flush. Roughly three void volumes pass through the sampling tubing at a flow rate of 1.2 l/min. during the thirty-minute flush. Assuming the annular fluid to be static, only approximately 20 mm (0.79 in) into the sand pack surrounding the screen are sampled. As a safeguard to assure a valid sample of the salaquifer water, at least one sample with a greatly increased flushing period should be taken for comparison. In studies made on microbial growth in wells sampled by back flushing it has been determined that the number of bacteria are greatly reduced after some extended time of back flushing. The question is raised whether or not these sampling methods reflect more than a sample of the conditions found in the annulus or at most the conditions in the surface of the sand-annulus interface.

These sampling methods are used for inorganic, organic, and microbial samples. DOC water samples are pressure filtered on site immediately after collection through a 0.45 μm silver membrane filter. The DOC sample bottle is a 50 ml glass serum bottle sealed with an aluminum foil covered rubber septum stopper.

Two samples are collected for standard inorganic analysis: one litre of filtered sample acidified to pH 2 with nitric acid for analysis of the cations, Al Ca, Fe, K, Na, Mg, and Zn; and one litre of non-acidified sample for anion analysis of Cl, F, SO_4, NO_2, NO_3, P, and silica. These samples are pressure filtered in situ through a 0.45 μm vinyl metricell membrane filter in a plexiglass filtration assembly, using



VALVE FOR UPPER SAMPLE
CONCRETE PAD
10" HOLE
10" HOLE
2" PVC SCREEN
2" PVC PIPE
SILICA SAND

Figure 195. A representative monitor well.

compressed carbon-free nitrogen to prevent the precipitation of ferrous iron. A 3.79 litre (1 gal.) sample is collected in an identical way for analysis of trace elements.

A one litre sample is collected without filtration for analysis of organic compounds. This sample in collected in a one litre glass bottle previously heated to 350°C (622°F) to free it of organic contamination. The sample bottle is sealed with a metal screw cap with a teflon gasket. The sample is placed in a molded styrofoam packer for shipment, and is chilled in crushed ice to minimize sample degradation.

Gas samples are collected by directing the outflow into an inverted 100 ml graduated cylinder filled with water, and the rate of gas collection is determined over a timed period at a measured flow rate. After measurement of the rate of gas effervescence, the inlet of a 250 ml cylindrical glass gas collector tube is attached to the sampling outlet, and the well water is allowed to flow through and displace air in the collector tube. Well water is then allowed to flow through the collector tube until 5 to 10 ml of gas are collected. The sample is sealed in the collector tube by simply closing the inlet and outlet stopcocks.

Measurements of pH, alkalinity, and specific conductance are performed on site, utilising fresh samples.

Biological samples were obtained by DiTommaso and Elkan[21] after flushing the wells for thirty minutes by collecting a 100 ml sample in a sterile serum bottle. The sample bottles were transported packed in ice to retard microbial growth.

Leenheer and Malcolm[21] used DOC as a parameter in determining the concentration of injected waste in monitor well samples. In order to establish base levels of DOC in various ground waters, Leenheer, et al,[23] analysed samples from 100 sites in 27 states. Values of greater than 5 mg/l DOC could indicate contaminent and possible pollutant organic materials. They did not advocate DOC as the absolute parameter and warned that certain organic materials such as pesticides can be toxic in concentrations below the detection limits of the organic carbon analysis.

CASE STUDY: BELLE GLADE FLORIDA

The United States Geological Survey undertook a study of the Belle Glade, Florida, industrial waste injection system in order to develop a better understanding of liquid toxic waste interactions with aquifer rock and native fluid, to determine movement and ultimate fate of the waste, and to develop a scientific basis for assessing the long-term environmental impact of subsurface waste injection.

Methods

Samples of injected waste, native aquifer water, and fluids from the zone of active waste-rock-native fluid interaction were taken periodically and analysed for geochemical, dissolved gases, and bacterial content.

Hydrogeology

The southern part of the Florida peninsula is underlain by early tertiary carbonate rocks at depths of about 457 m (1,500 ft.) to 1372 m (4,500 ft.). The carbonate includes several highly permeable cavernous zones filled with saline water and separated from one another by relatively impermeable carbonate and/or evaporite beds. The top approximate 305 m (1,000 ft.) of this cavernous zone is the lower part of the principal artesian aquifer of the southeastern United States. This aquifer consists mostly of middle Eocene to middle Miocene limestone and dolomite. The effective porosity of the aquifer and the underlying tertiary carbonate rocks is variable; however, in many places there are dense beds of limestone and dolomite which act as aquitards.

In the Belle Glade injection site the chloride content of the native salaquifer ranged from 1,650 mg/l at 457 m (1,500 ft.) to more than 7,000 mg/l at 579 m (1,900 ft.) at the time the injection well was drilled in 1966. See Table 24 for chemical analyses of native salaquifer water. The injection zone is separated from the overlying aquifer by 46 m (150 ft.) of dense limestone. The artesian head of the aquifer is about 17 m (57 ft.) above mean sea level. The altitude of the land surface is 4.6 m (15 ft.) above mean sea level. The slope of potentiometric surface indicates a flow towards the Atlantic ocean. Water moving through the Belle Glade area may ultimately discharge from submarine exposures of the salaquifer into the Straits of Florida (Figure 196).

Table 24. CHEMICAL ANALYSES-NATIVE-AQUIFER FLUIDS, BELLE GLADE AREA[1,3]

	Injection Well Depth [illegible] Feet	Deep Monitor Well Depth [illegible] Feet		Shallow Monitor Well Depth [illegible] Feet		[illegible] Well Depth [illegible] Feet		
Parameter	[illegible]	[illegible][2]	[illegible][2]	[illegible][2]	[illegible][3]	[illegible]	[illegible]	[illegible]
Alkalinity (as $CaCO_3$)	—	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]
pH (Units)	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	—
Calcium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Magnesium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Silica (SiO_2)	—	—	—	—	—	[illegible]	[illegible]	[illegible]
COD	—	—	[illegible]	—	—	—	[illegible]	[illegible]
Organic Carbon	—	—	—	—	—	[illegible]	[illegible]	—
Color (Units)	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]
Organic Nitrogen (N)	—	—	—	—	—	[illegible]	[illegible]	[illegible]
Ammonia (NH_3 as N)	—	—	—	—	—	[illegible]	[illegible]	[illegible]
Total Phosphate (as P)	—	—	—	—	—	[illegible]	[illegible]	[illegible]
Fluoride	[illegible]	—	—	—	—	[illegible]	[illegible]	[illegible]
Temperature (°C)	[illegible]	—	—	—	—	—	[illegible]	[illegible]
Specific Gravity (Dimensionless)	—	—	—	—	—	—	[illegible]	[illegible]
Sulfate	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chloride	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hydrogen Sulfide (H_2S)	—	—	—	—	—	—	[illegible]	—
SO_4/Cl Ratio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Analyses in milligrams per liter except as indicated.

[2] [illegible] courtesy of Black, Crow and Eidsness, Inc., Gainesville, Fla. [illegible], High Flow, [illegible] gpm; [illegible], Low Flow, [illegible] gpm.

[3] [illegible]

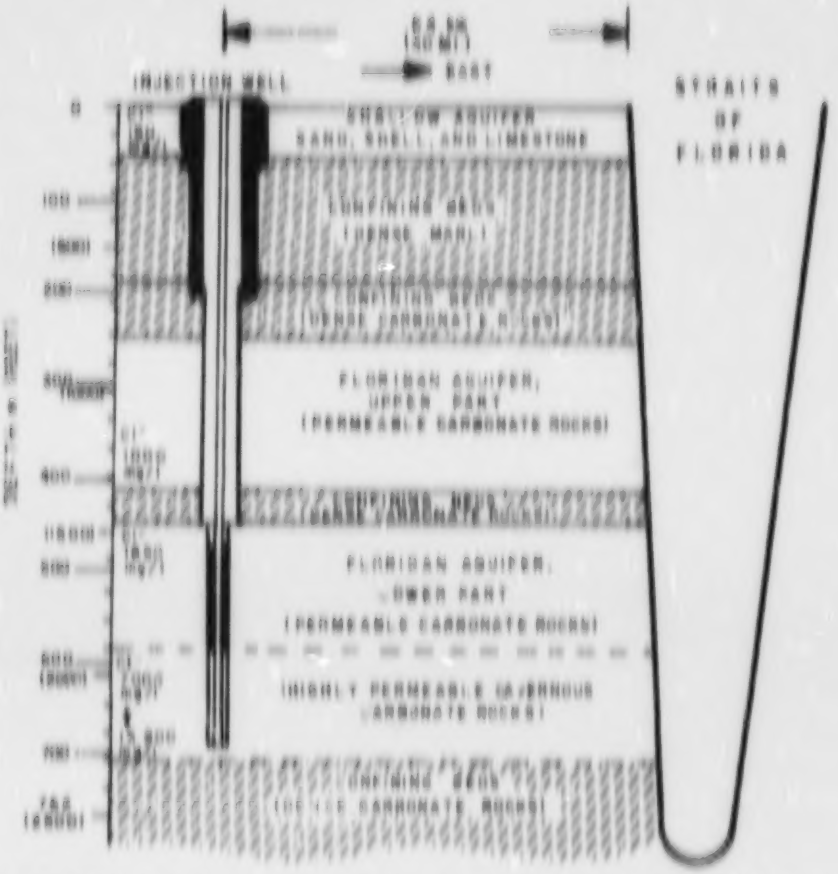

INJECTION WELL
EAST
STRAITS OF FLORIDA
SHALLOW AQUIFER
SAND, SHELL, AND LIMESTONE
CONFINING BEDS
(DENSE MARL)
CONFINING BEDS
(DENSE CARBONATE ROCKS)
FLORIDAN AQUIFER,
UPPER PART
(PERMEABLE CARBONATE ROCKS)
FLORIDAN AQUIFER,
LOWER PART
(PERMEABLE CARBONATE ROCKS)
HIGHLY PERMEABLE CAVERNOUS
CARBONATE ROCKS
CONFINING BEDS
(DENSE CARBONATE ROCKS)
0
100
200
400
500
600
700
mg/l

Figure 196. Schematic hydrogeologic section between Belle Glade area and Straits of Florida (partial data sources include Garcia-Bengochea and Vernon, Kaufman.[illegible]

The Injection System

The injection system consists of one injection well, one shallow monitor well, and one deep monitor well which also functions as a standby injection well. (Figures 197 and 198). The injection well was first cased to a depth of 456 m (1,495 ft.) with 304.8 mm (12 in.) casing, and an open-hole completion was made at 591 m (1,939 ft.) in the lower subaquifer. The injection tubing of 203.2 mm (8 in.) stainless steel was set at the bottom of the casing with a packer. During the fall of 1971, the tubing was extended to 591 m (1,938 ft.) and cemented. The well was then drilled to 683 m (2,242 ft.).

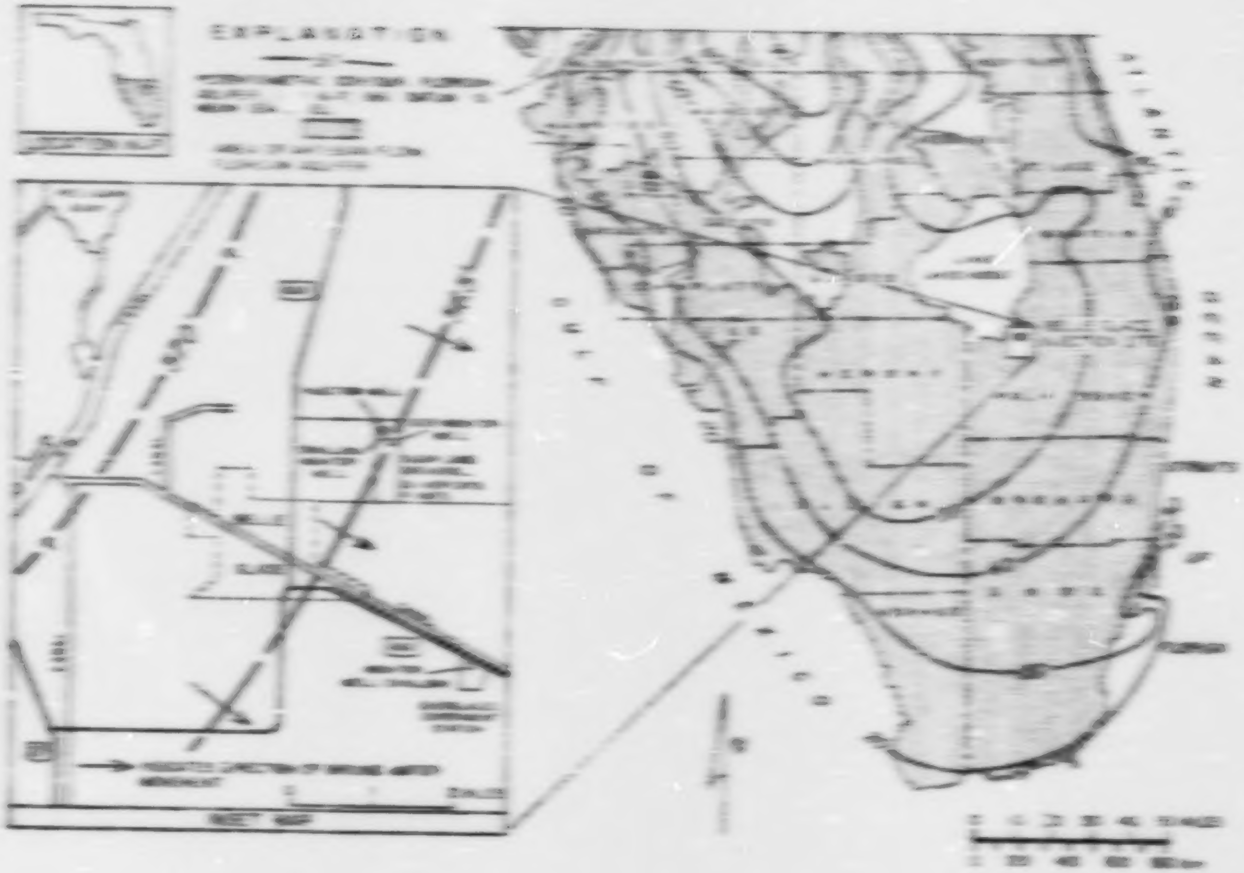

EXPLANATION
ATLANTIC
OCEAN
GULF OF MEXICO
BASE MAP

Figure 137. Index map of Belle Glade area and potentiometric-surface map of Floridian aquifer in South Florida.[23]

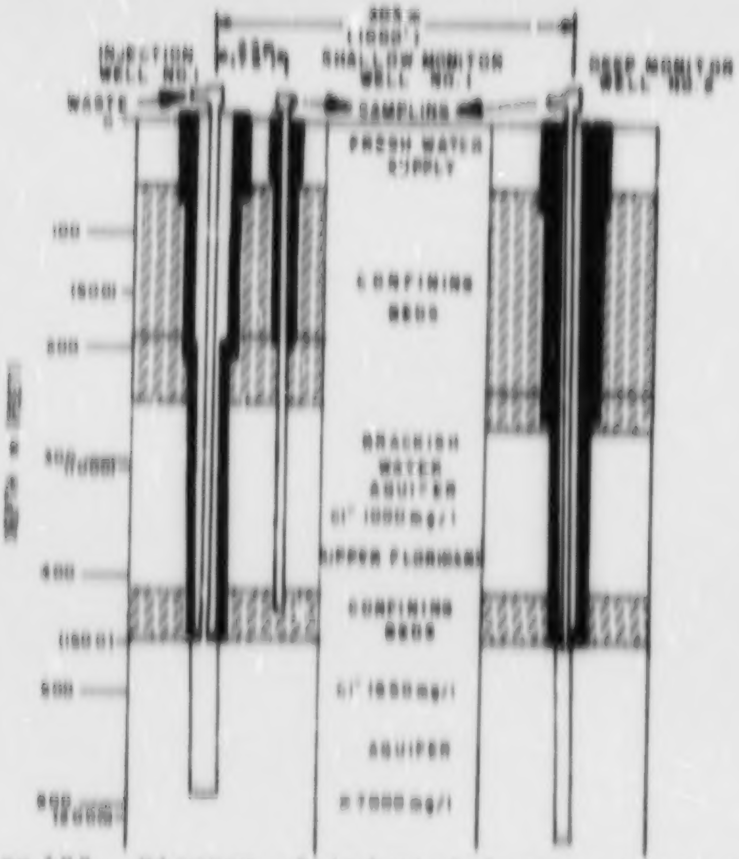

INJECTION WELL NO.1
SHALLOW MONITOR WELL NO.1
DEEP MONITOR WELL NO.2
WASTE
SAMPLING
FRESH WATER SUPPLY
CONFINING BEDS
BRACKISH WATER AQUIFER
UPPER FLORIDAN
CONFINING BEDS
AQUIFER
100
200
400
500

Figure 198. Diagram of industrial waste injection and monitoring system, prior to deepening injection well (after Garcia-Bengochea and Vernon).[illegible]

The deep monitor well is 305 m (1,000 ft.) southeast of the injection well for assessing effects in the injection zone. It is an open hole completion to a depth of 630 m (2,067 ft.), cased with 304.8 mm (12 in.) casing to 454 m (1,490 ft.), and has stainless steel 203.2 mm (8 in.) tubing set with a packer at the bottom of the casing.

The shallow monitor well is 23 m (75 ft.) south of the injection well for monitoring hydraulic and geochemical effects in the overlying aquifer. It is cased to 198 m (648 ft.), and completed in the open hole at 427 m (1,400 ft.).

Data were obtained from a University of Florida Everglades Experiment Station well 3.2 km (2 mi.) southeast of the Belle Glade site. This well is cased to 292 m (957 ft.) and completed in the open hole to 406 m (1,332 ft.).

The Waste

The injected waste is a hot, acidic, and highly organic effluent from a sugar mill and from the production of furfural, an aldehyde processed from sugar cane bagasse (Table 25). The temperature ranges from 71 to 103°C (160 to 217°F); the pH ranges from 3.6 to 4.5; the COD ranges from approximately 6,000 to 26,000 mg/l. (See Garcia-Bengochea and Vernon[11] for further operational information.)

Table 25. CHEMICAL ANALYSES -- INJECTED INDUSTRIAL WASTE, BELLE GLADE, FLORIDA.[11]

Parameter	10-20-71	1-21-72
Acidity (me/l)[2]	137	90
pH (Units)	[illegible]	5.1
Calcium	116	30
Silica (SiO_2)	[illegible]	16
COD	10,900	14,800
Organic Carbon	9,300	3,670
Color (Units)	500	1,000
Organic Nitrogen (N)	72	59
Ammonium (NH_4 as N)	27	0.6
Total Phosphate (as P)	26	8.5
Suspended Solids	2,490	1,880
Fluoride	8.6	5.0
Chloride	114	40
Temperature (°C)	91	88.3
Specific Gravity (Dimensionless)	1.0061	1.0037

[1] Analyses in milligrams per liter except as indicated.

[2] Acidity in milliequivalents per liter.

Operating History

Waste injection began in late 1966; it is seasonal with continuous fall, winter, and spring injection. The system is inactive in late summer. Injection rates vary from 1.52 X 10^{-3} to 5.05 X 10^{-2} m^3/s (400-800 gpm) at pressures from 2.07 X 10^5 to 4.14 X 10^5 Pa (30-60 psi). During 1966-1972 more than 3.0 X 10^6 m^3 (8.0 X 10^8 gal.) of waste were injected. The injection index:

$$\frac{\text{injection rate in gpm}}{(\text{pre-injection pressure}) - (\text{bottom hole pressure after injection})}$$

has increased more than fivefold, indicating a substantial increase in permeability near the well bore.

No pressure effects are evident in the two monitor wells. An increase in COD and a decrease in pH were detected in the deep monitor well in 1967, and in the shallow monitor well in the fall of 1969. The change in COD and pH in the shallow monitor well indicated upward migration of the waste front, either around the casing of the injection well or through the aquitards. Consequently the injection well was modified in the fall of 1971 as previously mentioned. During the modifications on the injection well, the deep monitor well was used for waste injection. More than 2.8 X $10^5 m^3$ (7.5 X 10^7 gal.) of waste under pressure of about 3.4 X 10^5 Pa (50 psi) were injected into the monitor well. See Figure 199 for the amount of waste injected over the study period. After completion of the modifications, waste injection was returned to the injection well.

Since the injection well was returned to use, the deep monitor well has been allowed to backflow continuously at 7.6 X 10^{-3} to 1.1 X 10^{-2} m^3/s (2-3 gpm) for geochemical analyses. In October 1972, a mechanical caliper log indicated that the injection well was plugged at 593 m (1,945 ft.). Indications were that all of the injected waste was exiting from the well bore into the salaquifer through two 2.4 m (8 ft.) caverns within the 6.7 m (22 ft.) interval below the casing. Apparently 4.6 m (15 ft.) of mild-steel casing extending from the bottom of the stainless steel casing at 591 m (1,938 ft.) had been perforated by corrosion.

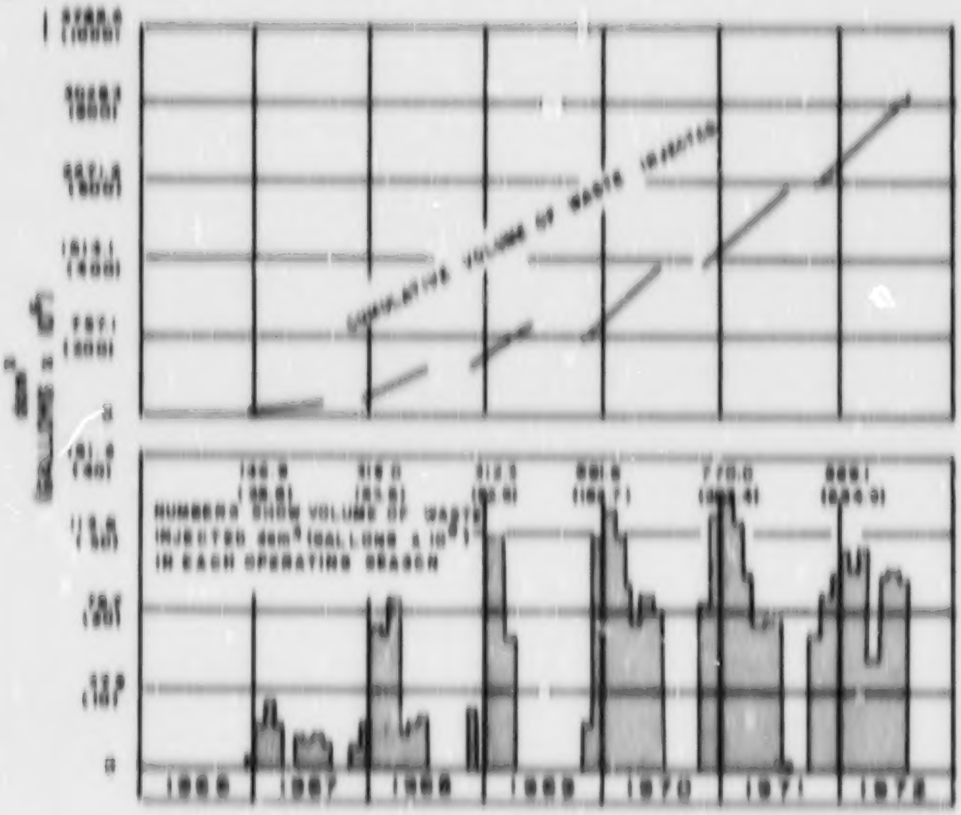


Figure 199. Volume of waste injected versus time.[88]

Results

Analyses of the injected waste are given in Table 25. The waste is hot, acidic, and highly organic. It also contains high concentrations of nitrogen and phosphorus. The organic carbon concentration exceeds 5,000 mg/l, and suspended solids exceed 1,800 mg/l. Chloride concentration is low compared to the native salaquifer water. The specific gravity of the waste ranges from 1.004 to 1.006. At 80° C (176° F) the estimated density of the waste is 0.98 g/ml, which is less dense than the native fluids which have a density greater than 1.003 g/ml at normal formation temperatures.

Analyses of native salaquifer fluids from the injection zone and the overlying aquifer are presented in Table 24. Chloride is 1,000 mg/l in the upper aquifer and 15,000 mg/l in the salaquifer. Besides the sodium chloride type there are appreciable quantities of sulfate, magnesium, and calcium. Analyses of injection zone fluids after waste injection are shown in Table 26.

Table 26. CHEMICAL ANALYSES -- INJECTION -- ZONE FLUIDS FOLLOWING WASTE EMPLACEMENT, BELLE GLADE, FLORIDA[28]

Parameter	Deep Monitor Well Depth 1490-2067 Feet 3-27-72 Residence Time > 75 days	Injection Well Depth 1938-2241 Feet 1-6-72 Residence Time ~160 day
Alkalinity (as $CaCO_3$)	3,030	3,477
pH (Units)	6.2	6.6
Calcium	1,100	1,100
Magnesium	700	700
Silica (SiO_2)	58	68
COD	6,610	4,168
Organic Carbon	3,870	2,430
Color (Units)	900	480
Organic Nitrogen (N)	7.8	3.8
Ammonium (NH_4 as N)	11	18
Total Phosphate (as P)	8	4
Fluoride	3.3	2.9
Sulfate	228	452
Chloride	1,300	8,000
Hydrogen Sulfide (H_2S)	68	78
SO_4/Cl Ratio	0.18	0.06
Temperature (°C)	40	28.8
Specific Gravity (Dimensionless)	1.0070	-
Eh (millivolts)	- 266	-

[a] Analyses in milligrams per liter except as indicated.

The pre-injection chloride content data show that the injection zone was within the brackish to saline transition zone before the well was deepened. Samples from the Experiment Station well show no change in the chemistry of native fluids in the upper aquifer for the last 40 years according to Stringfield.[26]

Geochemical effects associated with the upward movement of the waste front and dissolution of aquifer rock are shown from the shallow monitor well data from March, 1971, to March, 1972:

Parameter	Percent Deviation
Calcium	+150
Magnesium	+85
Alkalinity	+665
Sulfate	-42
Chloride	+10
SO_4/Cl ratio	-50

Table 27 shows analyses of water from the shallow monitor well.

Anaerobic Sulfate-Reducing Bacteria

A reduction in sulfate concentration and the appearance of hydrogen sulfide from March, 1971, to March, 1972, in the monitor wells suggests the presence of sulfate-reducing bacteria in the waste front. To detect and estimate the bacterial populations, serial inoculations of water from the monitor wells and the waste stream were made into Bacto-Sulfate Broth in March, 1972. (API Recommended Practice 38.)[27] Following inoculation the vials were observed daily

Table 27. CHEMICAL ANALYSES — SHALLOW MONITOR WELL, BELLE GLADE, FLORIDA[1,2]

	3-14-69[2]	3-5-69[2]	3-4-69[2]	3-30-71	10-20-71	3-30-72	9-26-72	11-21-72
Alkalinity (as $CaCO_3$)	118	132	157	902	898	902	843	853
pH (Units)	7.4	7.85	8.00	6.61	6.61	6.47	—	6.5
Calcium	99	105	118	258	252	250	270	280
Magnesium	57	42	101	190	182	190	190	170
Silica	—	—	—	21	28	23	28	19
COD	—	20	—	480	461	486	—	1,330
Organic Carbon	—	—	—	475	482	365	280	334
Color (Units)	1	1	2	30	40	20	40	120
Sulfate	364	357	363	196	218	215	310	380
Chloride	855	845	1,025	820	875	940	860	900
H_2S	—	—	—	65	90	85	—	—
SO_4/Cl Ratio	0.43	0.42	0.35	0.22	0.25	0.22	0.36	0.42
Suspended Solids	—	—	—	—	1	—	—	326

[1] Analyses in milligrams per liter except as indicated.

[2] Furnished courtesy of Black, Crow and Eidsness, Inc., Gainesville, Fla.

for three weeks. A positive for the sulfate-reducing bacteria was indicated by a blackening of the broth. The results from the four sampling sites are tabulated below:

Sampling Site	Serial dilution in ml					
	1.0	0.1	0.01	0.001	0.0001	0.00001
Waste stream	-	-	-	-	-	-
Deep monitor well	+	-	-	-	-	+
Shallow monitor well	+	+	+	-	-	-
Experiment Station well	-	-	-	-	-	-

The shallow monitor well was positive on a 0.01 ml dilution, indicating a population estimate of 100 cells/ml. The deep monitor well was positive for only a 1.0 ml (not diluted) indicating an estimate of 1 cell/ml. Note that no positives were found in the Experiment Station well, indicating no sulfate reducing bacteria in the upper aquifer within the study area.

Gas analyses of samples from the deep monitor well showed the presence of methane which indicates the presence of methane bacteria.

When a sample collected after 75 days residence time is "normalized" to the composition of native salaquifer fluids using chloride as a parameter because it does not undergo any geochemical or biochemical reaction, the following data indicate biochemical and geochemical activity:

Parameter	Normalized composition mg/l	Actual composition mg/l	Percent change
Chloride	1,300	1,300	0
Alkalinity as Ca CO_3	100	3,920	+3,800
Calcium	120	1,100	+ 820
Magnesium	125	700	+ 460
Silica	18	58	+ 220
Sulfate	420	220	− 45
Sulfate/chloride	0.32	0.18	− 44
Hydrogen sulfide	4	68	+1,600

CASE STUDY: WILMINGTON, N. C.

Hydrogeologic Conditions

The injection site is underlain by coastal-plain sedimentary units more than 305 m (1,000 ft.) thick. These sediments are mostly late Cretaceous and include the Tuscaloosa, Black Creek, and the Peedee Formations. Undifferentiated Pleistocene sands about 23-31 m (75-100 ft.) thick overlie the Cretaceous strata. These Pleistocene deposits generally consist of interbedded sand, silty sand, clay, and some thin beds of limestone. The sediments are fine grained; clay is the predominant lithic unit. The sands are in thin beds and are generally fine grained.

The surficial sands are the only aquifer beneath the site; are very permeable; and are a productive source of potable water. The recharge rate is high from most rainfall entering the sand. Individual wells yield about 1.89×10^{-2} m^3/s (300 gpm), and more than 2.63×10^{-1} m^3/s (6,000,000 gal/day) are withdrawn at the site.

There are several relatively permeable brackish artesian aquifers in the Cretaceous sediments at 91-107 m (300-350 ft.), 145-152 m (475-500 ft.), 203-213 m (666-700 ft.), and 259-312 m (850-1,025 ft.). The 91 m (300 ft.) zone was sampled at several sites and found to have a chloride content of 4,600 mg/l and an artesian head of 8.8 m (29 ft.) above sea level.

No data are available for the 152 m (500 ft.) zone, since no wells were completed at this depth.

Three wells have been completed in the 213 m (700 ft.) zone. Chloride content of the salaquifer water ranges from 8,500 mg/l to 12,500 mg/l. The artesian head of this zone is unusually high: 27 m (90 ft.) above sea level. No comparable pressures had been measured from Cretaceous salaquifers in North Carolina.

The injection zone salaquifer consists of multiple layers of sand, silty sand, clay, and some thin beds of limestone. The overall permeability of the injection zone is very low, although the more saline levels have a relatively high permeability. A temperature survey indicated that most waste entered a thin zone at 305 m (1,000 ft.) in the initial injection well.

Since no long-term pumping test was made on the injection well before the system was placed in operation, and the initial injection rates fluctuated greatly no data are available for the hydraulic characteristics of the salaquifer from the injection well. However, a 24 hour test was made on Well No. 2 which shows a transmissivity of 1.3×10^{-3} $m^3/s/m$ (9,000 gal/day/ft.). A sharp decrease in transmissivity after 23 minutes showed boundaries of low permeability within 30+m (a few hundred feet) of the injection well.

The high artesian pressure, particularly in the salaquifer; the low permeabilities of the salaquifers; the thick zones of clay and silty sands; and the shallow depth to the brackish water suggest slow circulation of water in the Cretaceous beds.

It is probable that discharge from the salaquifer is vertical and into the Cape Fear River.[18]

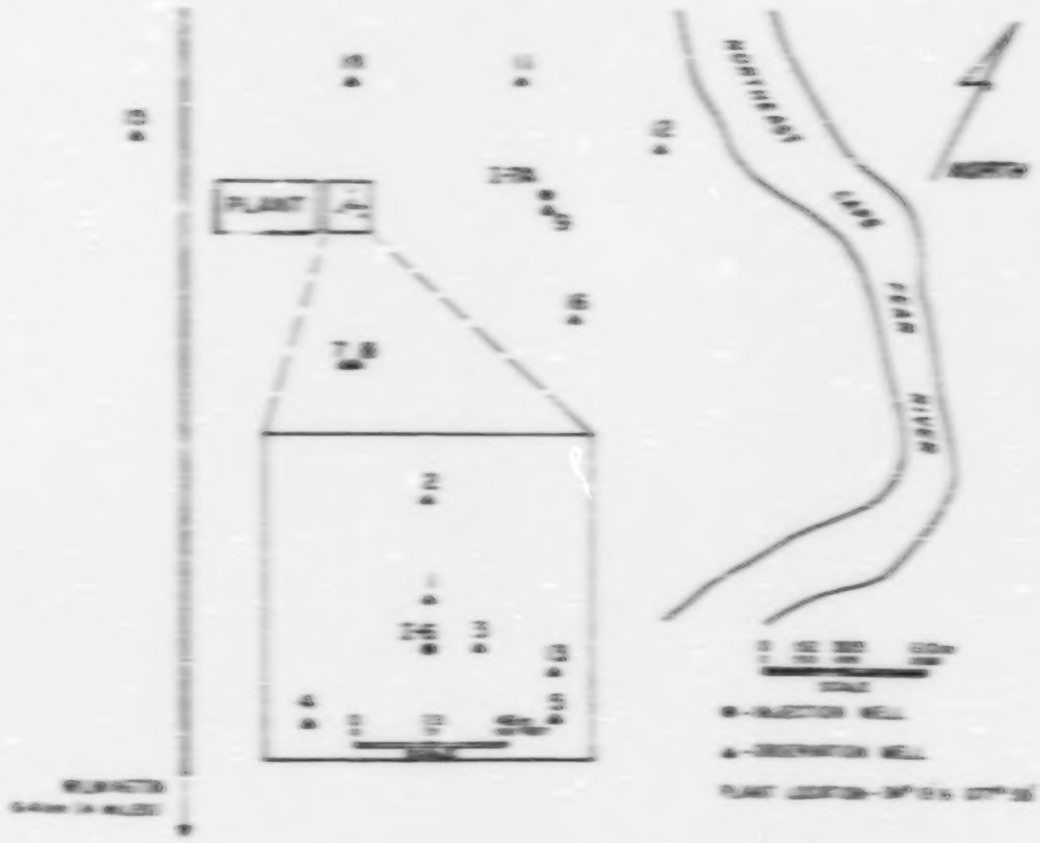

NORTHEAST CAPE FEAR RIVER
NORTH
PLANT
SCALE
●-INJECTION WELL
▲-OBSERVATION WELL
2
1
3
24
7
8
16
11
15

Figure 200. Map of the injection system

The Injection System

The initial injection system consisted of one injection well and four monitor wells completed at 312 m (1,025 ft.), and one monitor well completed in the first aquifer above the injection zone at 213 m (700 ft.) in May 1968. See Figure for a map of the injection system and Table 28 for a chronology of the waste injection operation. Monitor well 13 was installed in November, 1971, at 91 m (300 ft.) in an overlying aquifer to determine possible vertical waste movement.

In September 1968, the waste was present in samples collected from all wells completed in the injection zone. These monitor wells were located as far as 46 m (150 ft.) from injection well I-6. Waste injection continued until June 1969, when the injection pressure reached 1.35 X 10^6 Pa (196 psi). The injection permit set the maximum injection pressure at 1.03 X 10^6 Pa (150 psi). In an effort to reduce the pressure monitor wells 4 and 5 were used for waste injection. An unsuccessful attempt was made to reclaim I-6, and injection continued through the monitor wells until I-7A was completed in May, 1971.

Table 28. CHRONOLOGY OF WASTE INJECTION[88]

Date	Event
May 1968	Injection well I-6, and observation wells 1, 2, 4 and 5, completed at 312 m (1,025 ft.). Observation well 3 completed at 213 m (700 ft.).
May 1968	Waste injection begun through injection well I-6.
Sep. 1968	Waste was detected in wells 1, 2, 4 and 5.
Jun. 1969	Waste injection shifted from well I-6 to wells 4 and 5 because of excessive injection pressures in well I-6.

(Table 28. continued)

Nov.	1969	Injection well I-6 plugged during an attempt to reclaim. Waste injection continued through wells 4 and 5.
Dec.	1970	Observation well 8 completed at 213 m (700 ft.).
Jan.	1971	Observation well 9 completed at 213 m (700 ft.).
Feb.	1971	Leakage of waste into the 213 m (700 ft.) aquifer was detected at well 3.
Apr.	1971	Injection well I-7A was completed to 320 m (1,050 ft.).
May	1971	Waste injection shifted from wells 4 and 5 to well I-7A.
May	1971	Observation wells 7 and 11 completed at 320 m (1,050 ft.).
May	1971	Wells 1 and I-6 were cemented to stop waste-leakage into the 213 m (700 ft.) aquifer.
Jun.	1971	Observation well 12 completed at 320 m (1,050 ft.).
Oct.	1971	Waste injection renewed through well 0-4 because well I-7A was not accepting all the waste at the specified injection pressure limit.
Nov.	1971	Observation well 13 completed at 91 m (300 ft.).
Dec.	1971	Waste was detected in well 9 indicating waste leakage into the 213 m (700 ft.) aquifer.

(Table 28. continued)

Dec. 1971	Pressure decrease in well 5 indicated possible waste leakage into an aquifer above the injection zone.
Mar. 1972	Pressure decrease in well 2 indicated possible waste leakage into an aquifer above the injection zone.
May 1972	Observation wells 14, 15 and 16 were completed at 320 m (1,050 ft.).
Jun. 1972	Waste was detected in well 14, and a weekly sampling program was instituted to monitor the passage of the waste front.
Nov. 1972	Waste injection was gradually phased over to surface treatment of the waste.
Dec. 1972	Waste injection terminated.
Jan. 1973	Waste disappeared in well 14 after injection termination.

Waste leakage into the 213 m (700 ft.) salaquifer was suspected when the pressure increased in monitor well 3 in February, 1971. By March 1971, formic acid was detected in samples from monitor well 3, confirming that waste had reached the 213 m (700 ft.) zone. In May 1971, the casings of I-6 and monitor well 1 were filled with cement and the pressure dropped in monitor well 3, indicating that the leakage had been reduced or stopped. Additional leakage of waste from the injection zone into the 213 m (700 ft.) salaquifer was presumed because the pressure dropped in the injection zone at monitor well 5 in December 1971, and in monitor well 2 in March 1972. These wells were reported plugged in October 1972.

The Expanded Injection System

Injection well I-7A was drilled 762 m (2,500 ft.) northeast of I-6 and completed at a depth of 320 m (1,050 ft.) in April 1971. During the completion of I-7A waste and gas were pulled into the well. The gas was accidently ignited by welding equipment and later analysis showed the gas to be predominantly methane. The appearance of formic acid in water samples confirmed the presence of waste.

A second observation well network was installed at 10 to 15 times the distances of the initial monitor system to monitor waste movement from old and new injection wells. Monitor wells 11, 13, 14, 15 and 16 were installed from May 1971, to May 1972, for monitoring pressure and waste movement in the injection zone. Monitor wells 8 and 9, completed in the 213 m (700 ft.) zone, were operational when the second injection well was completed, (Figures 201 and 202.

The Waste

The injected organic waste is from the manufacturing of dimethyl terephthalate (DMT) used in the synthesis of polyester fibers. Prior to the injection the waste is moved through a settling basin, filtered to remove particles over 20 µm in diameter, and lime is added to adjust the pH to 4. The average composition of the waste is shown in Table 29. Organic constituents were determined prior to lime addition, and inorganic constituents were determined after lime addition. Dissolved organic carbon (DOC) is defined as that part of total organic carbon which passes through a 0.45 µm silver filter.

Almost three quarters of the DOC in the waste is composed of acetic and formic acids. The acidity of the waste after being neutralised to pH4 prior to injection is still such as to evolve 3.15 ml of CO_2 at STP per millilitre of the waste with calcium carbonate. The remaining one quarter of the DOC in the waste is mainly dicarboxylic aromatic acids.

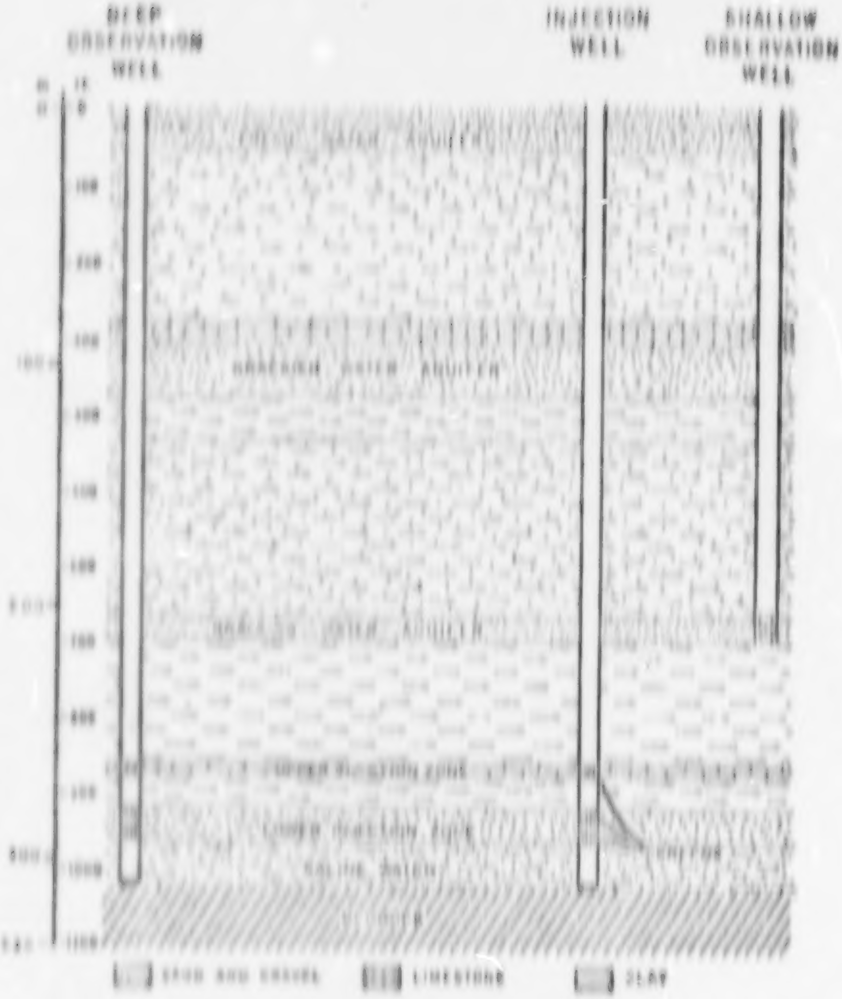
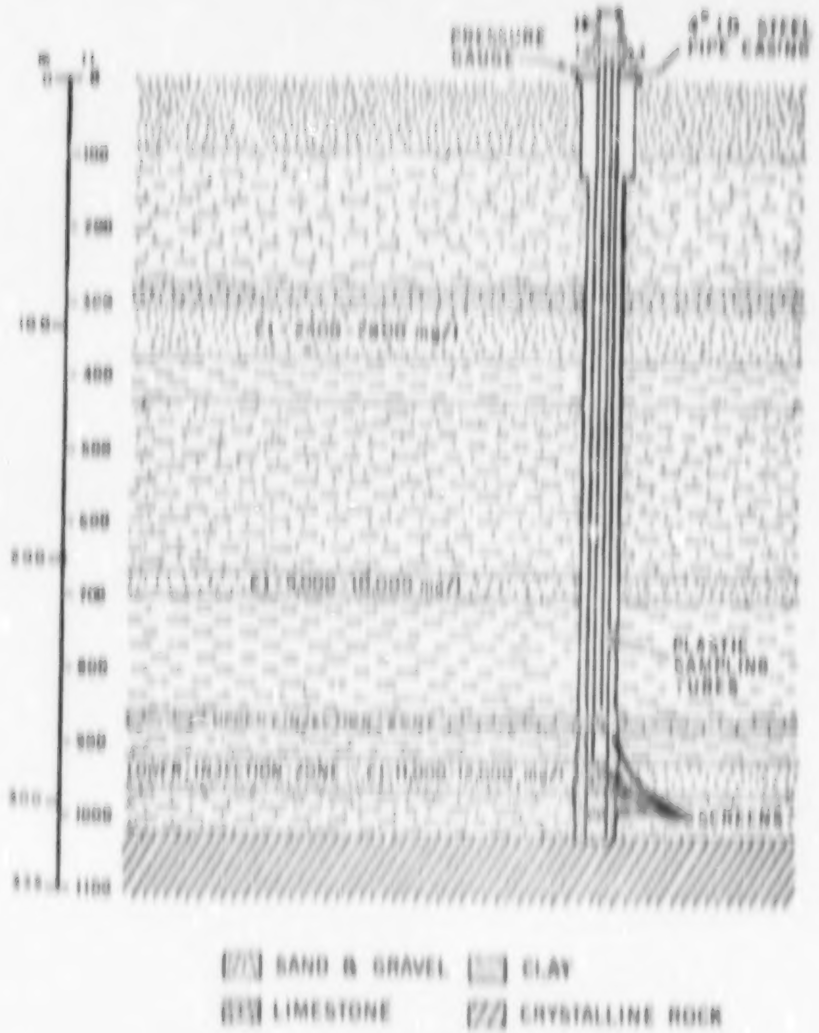

DEEP OBSERVATION WELL
INJECTION WELL
SHALLOW OBSERVATION WELL
m
ft
0
0
100
200
300
400
500
600
700
800
900
1000
1100
100
200
300
SAND AND GRAVEL
LIMESTONE
CLAY

Figure 201. Cross section of the injection and monitoring system.


m
ft
0
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100
200
300
100
400
500
600
200
700
800
900
300
1000
335
1100
PRESSURE GAUGE
4" I.D. STEEL PIPE CASING
Cl 2400-7800 mg/l
Cl 5000-10,000 mg/l
PLASTIC SAMPLING TUBES
LOWER INJECTION ZONE
SCREENS
SAND & GRAVEL
CLAY
LIMESTONE
CRYSTALLINE ROCK

Figure 202. Monitor well 14.

Table 25. PARTIAL CHEMICAL COMPOSITION OF INJECTED WASTE[11]

	Concentration (mg/l)	Dissolved Organic Carbon of Constituents (mg/l)	Percent Dissolved Organic Carbon
Dissolved Organic Carbon (DOC)		10,000	100
As:			
Acetic Acid	15,000	6,000	60
Formic Acid	5,000	1,300	13
Methanol	500	190	1.9
Phthalic, Isophthalic, and Terephthalic Acids	4,200	2,400	24
Calcium (Ca)	2,400		
Magnesium (Mg)	40		
Nitrate (NO_3)	3.9		
Orthophosphorus (PO_4)	1.3		
Residue on Evaporation at 180°C	5,300		
Specific conductance (μmhos/cm @ 25°C)	8,300		
pH	4.0		

Chemistry of Native Water

Leenheer and Malcolm[33] performed chemical analyses on samples of native salaquifer waters from uncontaminated monitor wells wherever possible for background data. There was variability in the water from each well within the samw salaquifer (Table 30). However, the variations were minor from samples within the injection salaquifer. Wells 11 and 12 were screened in the injection zone, and wells 8 and 9 were screened in the salaquifer near the 213 m (700 ft.) level.

The high iron content in the samples from well 9 causes a red iron oxide precipitate, and the high sulfide content in water from well 8 causes black sulfide precipitates after sampling. DOC concentrations in the native ground water ranged from 0.2 to 4.0 mg/l. Since the DOC concentrations of the injected waste ranged from 10,000 to 12,000 mg/l, only a small percentage of injected waste in the ground water was necessary to significantly raise the DOC concentration. DOC was used to simply and conveniently measure organic waste occurrence in the ground water.

Waste - Salaquifer Interactions

Data on waste-salaquifer interactions were obtained during passage of the waste front through wells 1, 2, 4, and 5 during the first four months of waste injection (May - September, 1968). Samples from wells 2, 4, and 5 indicated that interactions had occurrud between the undiluted injected waste and the salaquifer (Table 31). Water samples obtained from well 14 between June 1972 and January 1973, showed major changes and interactions of the waste after it had moved a distance of 457 m (1500 ft.) laterally through the injection zone during a 4 year period after injection.

Residue on evaporation and pH measurements by Hercules, Inc., during the first months of waste injection indicated that by July 1968, the waste was already present in well 1, 15 m (50 ft.) from injection well 1-6, while monitor well 5 at a distance of 46 m (150 ft.) was waste free.

Table 31. CHEMICAL ANALYSIS OF WASTE AQUIFER WATER*

	Observation Well 11	Observation Well 12	Observation Well 8	Observation Well 9
Date of collection	11-03-71	11-03-71	06-15-71	06-15-71
Depth of sampling (feet below land surface datum)	935 285m	945 288m	695 212m	725 221m
Silica (SiO_2)	8.6	9.0	8.8	8.2
Aluminum (Al)	.19	.45	.50	.31
Iron (Fe)	1.70	5.30	2.20	12
Manganese (Mn)	.33	.27	.18	.18
Calcium (Ca)	537	427	265	302
Magnesium (Mg)	195	270	321	438
Sodium (Na)	6,600	6,650	5,900	6,750
Potassium (K)	330	320	212	230
Lithium (Li)	.28	.29	-	-
Bicarbonate (HCO_3)	232	233	358	244
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	210	250	622	740
Chloride (Cl)	12,000	11,900	9,650	11,400
Fluoride (F)	.6	.6	.5	.4
Nitrate (NO_3)	< .1	< .1	.8	.6
Orthophosphate (PO_4)	< .1	< .1	.02	.02
Hydrogen sulfide (H_2S)	.2	.3	2.1	.6
Copper (Cu)	.25	.26	.12	.27
Zinc (Zn)	.11	.05	.04	.04
Residue on evaporation at 180°C	19,500	20,000	17,200	20,000
Specific conductance (umhos/cm @ 25°C)	32,000	32,000	27,100	31,100
pH	7.2	7.2	7.5	7.4
Dissolved organic Carbon (DOC)	.6	.4	1.5	1.1

*Chemical constituents are reported in mg/l

Table 11. COMPARISON OF WASTE-FREE AND WASTE-CONTAMINATED GROUND WATER FROM MONITOR WELLS.

WELLS 4 AND 5 CONTAMINATED; 7 AND 11 WASTE FREE.1/

Well	Specific conductance (micromhos at 25°C)	pH	SiO_2	Al	Fe	Mn	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	B	NO_3	DOC
7	10,500	7.3	13	0.3	2.8	0.2	711	107	4,800	730	230	280	11,000	0.9	<.1	<.1	2.2
11	10,000	7.2	8.6	.2	1.8	.3	540	195	4,600	730	230	210	11,000	.4	<.1	<.1	.7
4	9,280	4.3	23	4.8	8.2	.3	2500	34	2.9	2.2	0	8.0	400	1.3	1.3	1.3	10,600
5	8,280	4.3	34	7.1	8.3	.3	2400	48	3.2	2.3	0	19	140	1.3	1.1	3.9	11,200
Contaminated (4 + 5) Uncontaminated (7 + 11)			2.9	38	5.1	1.0	3.9	0.27	.0006	.0009	0	0.065	0.02	1.7	*	*	11,500

Monitor well 5 remained waste free until the beginning of October, when evaporation residue and pH decreased, indicating the arrival of the waste front. The pH decreases because of the acidity of the waste, and the dissolved solids decrease because the salaquifer water is diluted by the waste which has a smaller evaporation residue. The organic acids of the waste react with the carbonate minerals in the injection zone to form organic salts of calcium and magnesium. These organic salts in solution are neutral to alkaline; therefore, the carbonate minerals act to neutralize the organic acids in the waste.

A waste front zone in which organic acids are neutralized is indicated in the data from monitor well 1. From July 28, 1968, to October 15, 1968, the pH remained between 5 and 6, while salaquifer carbonates reacted with the waste. When the waste-carbonate reaction ceased, the ph abruptly decreased to the pH of the injected waste and has remained at this level. Evaporation residue also decreased to the level of the injected waste.

Water samples collected while the waste-carbonate reaction was progressing contained large amounts of dissolved CO_2 which is a product of the acid-carbonate reaction. A sample of gas which effervesced from a sample collected from well 2 contained 85 percent CO_2 by volume. Wells 3 and 9 yielded similar CO_2 rich samples after the 213 m (700 ft.) salaquifer became contaminated with waste.

Complexation of organic acids and alumino-silicate dissolution are believed to occur between the salaquifer minerals and the undiluted waste in the region behind the waste front. High concentrations of silica, aluminum, and iron were found in water samples from behind the waste front. These increased concentrations over the native salaquifer water concentrations may indicate clay mineral dissolution. Table 31 compares the dissolved constituents of two contaminated monitor wells with two uncontaminated monitor wells.

The first period of sampling (January 20, 1972, to August 1, 1972) in well 14 (injection zone monitor well) showed an increase in DOC as evidence of waste in the well. No gas was found in a sample collected on August 1, 1972, but gas appeared in a sample two days later, and DOC rapidly decreased. From August 3, 1972, to October 31, 1972, the amount of gas increased while DOC did not increase at the rate prior to the appearance of gas. Table 32 summarized as analyses during this period.

Leenheer and Malcolm[88,89] suggest that the appearance of gas which coincided with the abrupt decrease in DOC marked the beginning of anaerobic microbial decomposition of the organic waste. Microbial populations have a lag time between the introduction of suitable media and rapid population increase. The waste concentrations may become too high to support microbial metabolism.

Samples collected from August 3, 1972, to November 22, 1972, contained gas with methane concentrations up to 60 percent of the total gas volume. Dissolved iron concentration fluctuated, but tended to increase with gas evolution, suggesting microbial reduction of ferric iron to more soluble ferrous iron. In samples collected up to September 4, 1972, black sulfide precipitates and hydrogen sulfide gas indicated the presence of sulfate reducing bacteria. Methane production, iron reduction, and sulfur reduction are probable indices of anaerobic bacterial metabolism induced by waste in the ground water.

Table 32. GAS ANALYSIS FROM WELL 14.[88]
VOLUME IN PERCENT OF TOTAL GAS VOLUME.

Date of Sampling	H_2	N_2	CH_4	CO_2	H_2S
8-01-72	0.5	26	61	11	ND*
8-07-72	ND	22	54	12	0.2
8-14-72	0.2	21	52	11	0.6
10-11-72	ND	29	48	11	ND
11-02-72	ND	62	33	3.8	ND
11-22-72	ND	68	13	1.5	ND

*Not detectable.

Role of Bacteria

DiTommaso and Elkan[11] obtained samples of water flushed from monitor wells, as well as samples of the waste before injection. Samples were taken of unpolluted, as well as polluted monitor wells. The samples were taken weekly or biweekly, depending upon DOC levels. The samples were incubated at 32°C (90°F) overnight, after which serial dilutions in triplicate were performed on all samples.

Polypeptone-peptone plates were innoculated from the dilutions and incubated for three days at 32°C (90°F) in anaerobic jars. (Figure 20) Colony counts were made; individual colonies were restreaked on polypeptone-peptone agar and stored at 5°C (21.5°F). Isolated bacteria from polluted and unpolluted monitor wells were identified to genus using Bergey's Manual (Breed, 1957) as a methods reference (Table 13).

No bacteria were found in the waste prior to injection or in the monitor wells which had a high concentration of waste. Laboratory innoculations of the waste showed no growth. Approximately 3,000 organisms per millilitre were present in the unpolluted salaquifer water from well 11, 320 m (1050 ft.) in the injection zone, and this count remained constant. These native bacteria were identified as the following genera: *Agrobacterium*, *Pseudomonas*, *Proteus*, *Bacillus*, *Aerobacter*, *Corynebacter*, *Arthrobacter*, *Micrococcus*, and *Pseudomonas fluorescens* group. These organisms are facultative or aerobic genera representative of the normal microflora of aquatic environments.

Isolates of the genera from well 11 samples were innoculated singly or in combination into a medium in which various dilutions of the waste served as the sole carbon and energy source. None of the isolates was able to metabolize the waste under these conditions.

A very low number of obligate anaerobes were detected from well 11. Since there is little or no organic-energy substrate in the unpolluted salaquifer, these organisms can be present only in limited numbers.

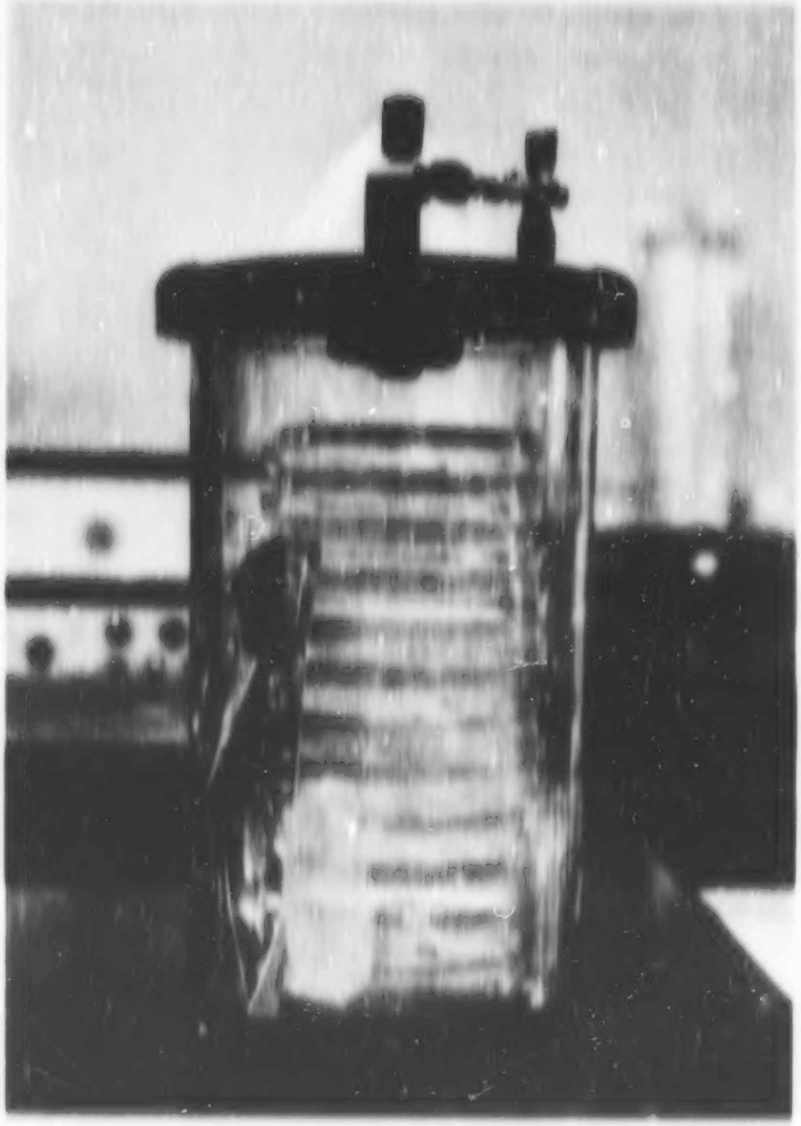

Figure 203. Anaerobic jar with disposable gas-generator envelopes and anaerobic indicators containing plates. (Bioquest, Cockeysville, Md.)

Table 33. IDENTIFICATION OF ISOLATES FROM UNPOLLUTED DEEP WELL (WELL 11)[22]

Organism Identified	Gram stain	Morphology	Motility	Sulfide Production	Reduction of Nitrate	Catalase Production	Starch Hydrolysis	Indole Production	Carbohydrate Utilization				
									Sucrose	Mannitol	Lactose	Glucose	Maltose
Agrobacterium	−	Rod	+	−	−	+	−	−	−	−	−	A	A^w
Pseudomonas	−	Rod	−	−	+	+	−	−	A	Ag	Ag	Ag	Ag
Proteus	−	Rod	+	−	+	+	−	−	A	Ag	Ag	A	Ag
Bacillus	+	Rod	−	−	+	+	+	−	−	A^w	A^w	A	A
Aerobacter	−	Rod	−	−	+	+	−	−	A	Ag	Ag	Ag	Ag
Corynebacterium	+	Rod	−	−	+	+	−		−	A	A	A	−
Arthrobacter	−	Rod	−	−	+	+	+	−	A	A	A	A	A
Micrococcus	+	Cocci	−	−	+	+	−	−	−	−	A	A	A
Pseudomonas fluorescens group	−	Rod	+	−	+	+	+	−	−	−	−	−	A^w

Key:
A - acid produced; + - positive reaction
G - gas produced; − - negative reaction
Ag - acid and gas produced; A^w - weak positive reaction

When the waste front reached well 14, the bacterial population count increased from 3000/ml to 1 million/ml (Table 34). When the ratio between bacterial counts and DOC is compared to time, a proportional increase in bacterial populations as the waste content of the salaquifer water increases, is evident (Figure 204). The plate counts were compared to direct microscopic counts of the samples from well 14. These direct counts remained approximately 1000 X higher than the plate counts. It is postulated that (1) mortality in anaerobic culture or (2) barophilic effects were responsible. However, the ratio between actual microscopic counts and plate counts remained constant, and a constant plate count sample could be assumed.

Methane Bacteria

When the gas content of well 14 reached 53 percent methane, it was assumed that the small population of obligate anaerobic methane producing bacteria had greatly increased. The combination of methane production and decreases in DOC support this assumption.

The waste diluted to 10 percent in salaquifer water from the injection zone supported growth of the methane bacteria in culture. After one week incubation periods, methane composed 42 percent of the atmosphere in the anaerobic jars.

The methanogenic bacteria were isolated in pure culture and were tentatively identified as belonging to two genera: *Methanobacterium* and *Methanococcus*.

A BIOGEOCHEMICAL MODEL

A biogeochemical model of waste movement and transformations after subsurface injection is presented in Figure 205. This model is modified from a geochemical model proposed by Leenheer and Malcolm[11]. The leading zone of the waste front is called the dilution zone because the waste appears as a dilute solution in the native salaquifer water. The zone following the dilution zone is called the microbial zone because of anaerobic bacterial metabolization of the dilute waste as a substrate for methane production. The next zone, the transition zone, is where the waste concentration increases to a level unfavorable for bacterial metabolism. In

Table 34. COMPARISON OF MICROBIAL COUNTS, ORGANIC CARBON, PERCENT METHANE, AND IRON CONTENT OF SAMPLES OBTAINED FROM WELL 14.[22]

Sampling	Microbial Count Colony Forming units/ml	Dissolved Organic Carbon mg/l	Methane Percent	Iron Content µg/l
6-1-72	1.0×10^3	20	1	2.01
6-6-72	2.3×10^3	30	3	2.09
7-7-72	3.0×10^3	20	1	3.76
7-17-72	3.5×10^3	102	2	6.12
8-1-72	5.8×10^5	112	5	5100
8-7-72	5.2×10^6	32	70	6200
8-15-72	6.0×10^6	20	51	5300
8-28-72	5.8×10^5	45	40	5600
9-6-72	5.2×10^5	42	8	8100
9-13-72	7.0×10^5	55	2	13000
9-20-72	7.1×10^6	58	32	12000
10-11-72	7.2×10^5	75	7	35000
10-31-72	8.3×10^3	60	5	36030
11-2-72	1.0×10^5	18	30	34000
11-7-72	1.9×10^5	14	10	18000
11-13-72	1.1×10^5	11	5	11000
11-27-72	9.5×10^3	10	21	8600
12-5-72	9.5×10^5	6	1	3630
12-11-72	9.7×10^5	21	1	5200
12-19-72	9.6×10^5	1	25	1800
12-29-72	9.0×10^5	5	1	1600

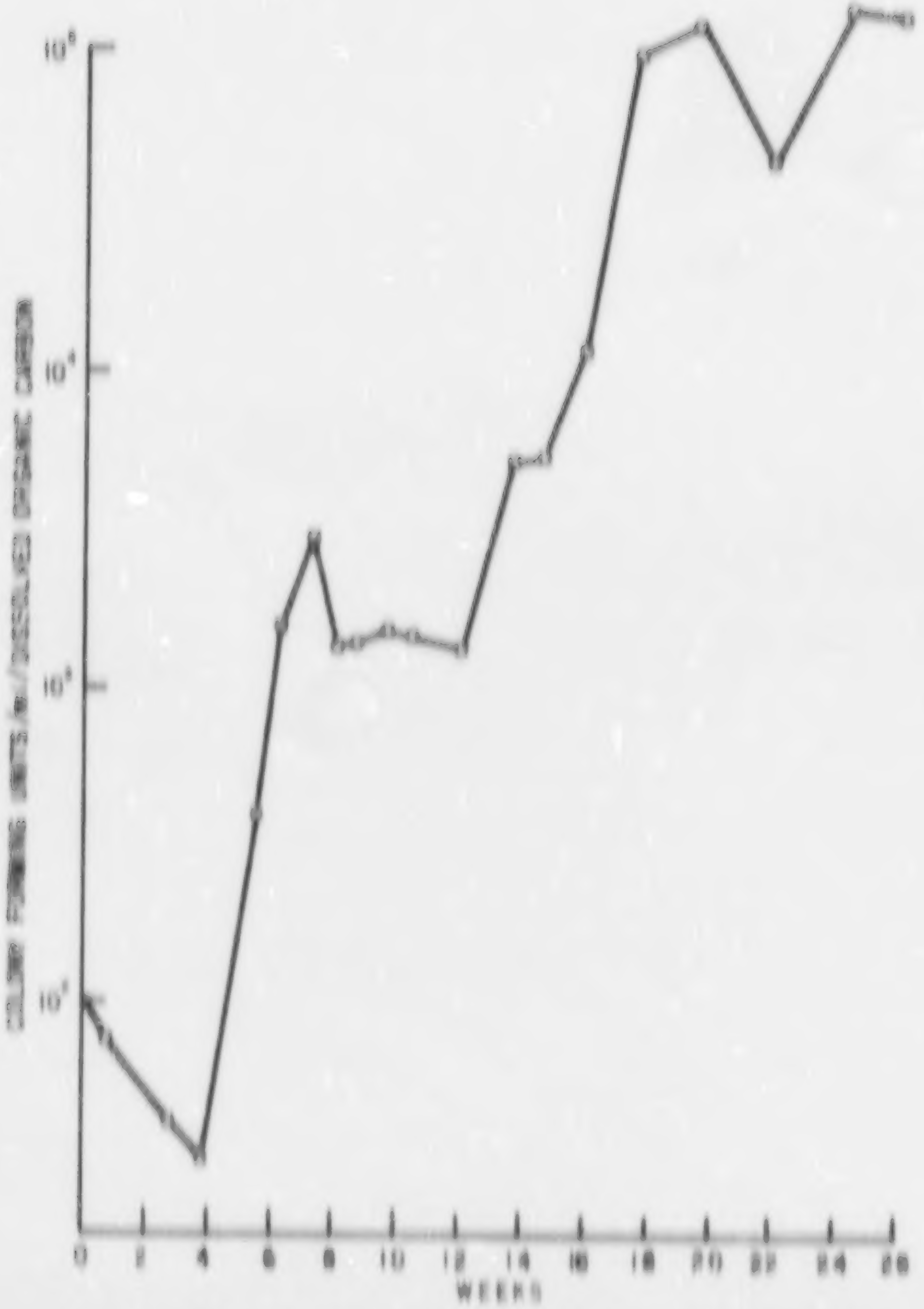

Figure 204. Ratio of number of bacteria to DOC (mg/l) in waste front (well 14).[77]

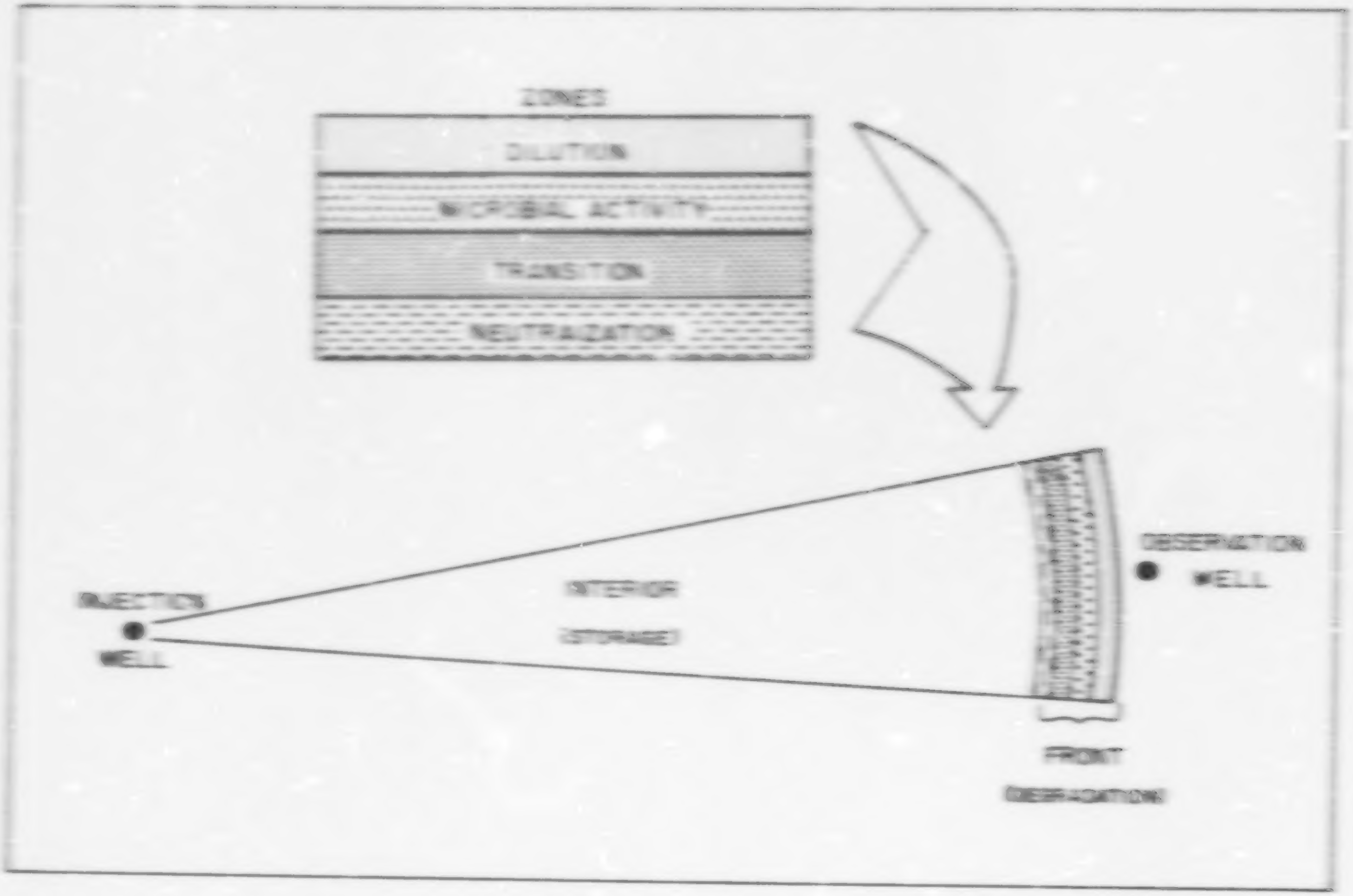
ZONES
DILUTION
MICROBIAL ACTIVITY
TRANSITION
NEUTRALIZATION
INJECTION WELL
INTERIOR
(STORAGE)
OBSERVATION WELL
FRONT
(DEGRADATION)

Figure 205. A biogeochemical model of waste movement and transformation. (After Leenheer and Malcolm).[21]

this zone there is a transition from microbial activity to the predominantly geochemical reactions of the neutralization zone. This zone probably constitutes the major area of physical change.

All of the four previously described zones in the model constitute the waste front. The waste is diluted by the native salaquifer water, transformed by methanogenic bacteria populations, and neutralized by geochemical reactions with the salaquifer minerals. The region where little dilution or transformation of the waste occur, is called the waste interior. The waste interior is where complexation and dissolution reactions occur in the salaquifer by the organic acids in the relatively undiluted waste.

RESEARCH IN PROGRESS OR IN REVIEW

A Biogeochemical Laboratory Study

J. A. Leenheer, R. L. Malcolm, and W. R. White[77] have completed studies on the physical, chemical, and biological aspects of subsurface waste injection near Wilmington, N. C. This study, which was completed in April 1974, is still in review, but should be available soon. Dr. Leenheer was most kind in allowing this writer to view his research facility and read his draft as it was prepared for review by the USGS. Various instrumental and experimental capabilities for surface-water organic studies were adapted and modified for organic investigations of transformations occurring in the injection zone of the Wilmington site. Columns were charged with the salaquifer minerals, and salaquifer water and waste were introduced under pressure. Every effort was made to simulate the injection zone conditions in a laboratory mock-up. The reactivity, fate, and movement of the waste were analyzed with methods including gas chromatographic, electrophoretic, and mass-spectrometric, as well as elemental and infrared analyses. When this paper is published, it should be the most complete investigation in existance covering the biogeochemical aspects of an injected waste operation.

A Microbial Laboratory Study

G. H. Elkan, C. Willis, and E. Horvath[77] are investigating the role of microorganisms in the decomposition of deep well injected wastes near Wilmington, N. C. The objectives of their research project are to develop sampling and isolated indigenous microorganisms from deep aquifers as a necessary prerequisite to determining changes that may occur in microbial populations resulting from waste injection. Due to the limited funds available, the project has abandoned research in sampling techniques. The project is now focused on the roles of indigenous bacteria in degradation of the waste constituents and positive identification of the organisms involved.

Mass cultures are grown in one litre flasks which are first filled with sterile sodium acetate and sodium formate broth buffered at pH 7.5 which simulates the dilute waste in the native salaquifer injection zone. The cultures are topped-off at one litre with native salaquifer and waste fluid from a monitor well under sterile conditions. These one litre culture flasks are equipped with gas collectors for quantitative analysis of any gases evolved by the action of the bacteria. Figure 206 shows a mass culture flask and the gas collector apparatus. When this writer visited the research facility in August, 1974, no gas had been evolved in the mass cultures, however, a black precipitate had formed, presumably from the action of sulfate reducers. The investigators plan to study the transformations of various wastes from other injection sites with similar apparatus during the course of their study.

Some preliminary work has been done with roller tube cultures in pressure chambers (Figures 207, 208 and 209). Pressure is transmitted hydraulically through a rubber diaphragm cap to the culture. Preliminary results show that as pressure increases to 1.72×10^7 Pa (2500 psi) growth rate drops to one-half that at 1 atmosphere. These results cast doubt on the hypothesis that the methane producing bacteria are barophyllic.

Roller tube cultures of isolates cultured in an atmosphere of hydrogen and carbon dioxide have produced methane. Figure 210 shows the white colonies of methane producing bacteria in a roller tube culture.

As the study progresses, it is hoped that a positive identification of the methane producing bacteria will be possible.

It is also intended to develop a model of population changes in the configuration of species under differing conditions of waste-salaquifer concentrations.

Figure 206. Mass culture for quantitative gas analysis.

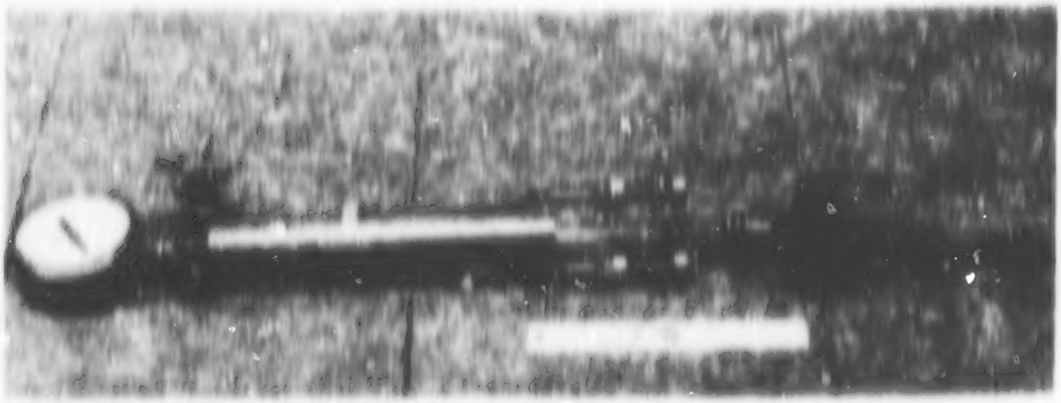

Figure 207. Pressure chamber showing pressure culture tube partially inserted.

Figure 208. Pressure chamber culture tube showing diaphragm seal cap.

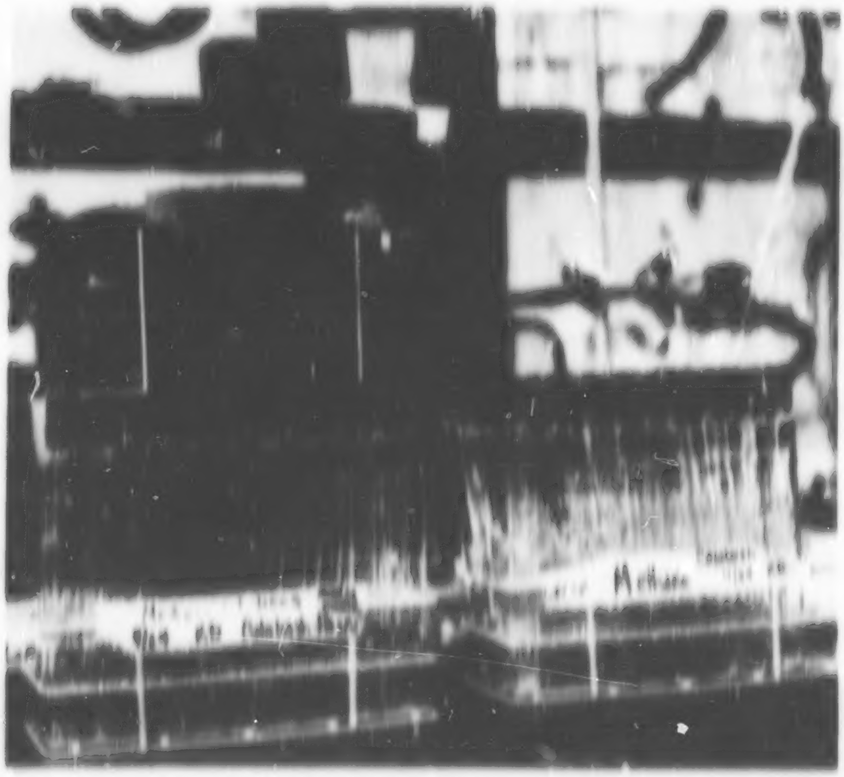

Figure 209. Method of filling and sampling gases in culture tubes.

Figure 210. Methane bacteria colonies (white circles) in gas filled culture tube. 4x

Bacterial Dissimilation of Phenolic Pollution

Riha, Millis, and Pinniger[11] are testing the effectiveness of newly developed borehole techniques for beneficiating groundwater polluted with high concentrations of phenolic compounds in basalt aquifers west of Melbourne, Australia. High concentrations of phenolic compounds have been observed in groundwater occurring in a series of observation bores surrounding a quarry used for disposal of industrial effluent. Phenol oxidizing organisms are known to be present in the groundwater. It is proposed to use special intra-well flow devices to induce regulated flow from the upper, more polluted aquifer to the lower aquifer which is at a slightly lower head. It is anticipated that this transfer will serve two functions, both of which will tend to improve the quality of the polluted groundwater: (1) Dilution by mingling with relatively unpolluted water in the lower aquifer. Over a period, water will be drawn in from less polluted parts of the upper aquifer surrounding the highly polluted phenolic zone. (2) Aeration of the descending water should promote development of the phenol-oxidizing organisms already present, thus providing improved conditions for dissimilation of the phenolic pollution.

Hydrogeological results will be analyzed by Mr. Riha and microbiological results by Dr. Millis.

SECTION XI

APPENDIX F

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SECTION XI

APPENDIX G

SUMMARY OF RESEARCH RELATED TO DEEP-WELL INJECTION

The research projects summarized in this appendix have been grouped by subject matter which may be identified by key letters indicated in the following legend.

Area Studies - - - - - - - - - - - - - - - A
Biological Studies - - - - - - - - - - - - - B
Chemical Studies - - - - - - - - - - - - - - C
Engineering Studies - - - - - - - - - - - - E
Geological and Hydrogeological Studies - - GH
Geophysical Studies - - - - - - - - - - - - GP
Monitoring Studies - - - - - - - - - - - - - M
Miscellaneous Studies - - - - - - - - - - - MI

AREA STUDIES

A-1

Artifical recharge of treated sewage water at Bay Park, New York

Performing Organization

U. S. Department of the Interior
Geological Survey
Mineola, New York 11501

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

The objective is to evaluate the feasibility of and develop optimum methods for injecting water from highly treated sewage-plant effluent into deep artesian sand aquifers of the Magothy (?) Formation (upper Cretaceous) of Long Island. This formation, which is the principal source of the water supplies for Nassau and western Suffolk counties, is being pumped intensively and locally is being invaded by salty water. Extensive artificial recharge through injection wells with reclaimed waste water may be needed for water conservation and to create fresh water pressure ridges to retard sea water.

Water from sewage-plant effluent will be further treated to a potable quality and then injected under pressure through specially designed wells (with fiberglass casings) under various experimental conditions. Data on hydraulic and geochemical results of the injection will be collected using observation wells and special in-situ geochemical sensors.

A-2

Saline Water Investigations, Kentucky

Performing Organization

U. S. Department of the Interior
Geological Survey
Louisville, Kentucky

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$10,000

Summary of Project -

Saline water is an integral part of Kentucky's water resources and is being evaluated along with the fresh water resource. Knowledge of the saline-water resource is of importance in the protection and management of fresh water resources and in the planning for underground disposal of wastes, and is of potential importance in areas where fresh water is in short supply.

Evaluate the occurrence and movement of saline water in Kentucky and its relation to fresh water. Determine the chemical quality of saline water, particularly of brines that may have commercial value.

Prepare a general statewide map showing the depth to the fresh-saline water interface. Define in detail the position of the interface and the movement of fresh water and brine in several near-surface aquifers such as the salt sands of the eastern coal field. Determine the occurrence and movement of water in the Knox dolomite. Collect and analyze brine samples, sampling and analysis of brines from oil field development, and preparation of data on chemical quality for computer storage.

Continuation of sampling analysis, and computerizing of data. Prepare statistical analysis of chemical data by aquifer and prepare map of selected chemical constituents by aquifer.

A-1

Wilcox waste disposal appraisal, Gulf Coastal Plain

Performing Organization

U. S. Department of the Interior
Geological Survey
Bay St. Louis, Mississippi

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$72,000

Summary of Project -

This research is to develop knowledge and understanding of subsurface environments of the Gulf Coastal Plain necessary for appraisal of their suitability for liquid waste storage; and to analyse and interpret data obtained using new concepts and principles of sedimentary basin hydrology, to make semi-quantitative determinations of the phycical characteristics and geometry of reservoir rocks, the chemistry of interstitial waters, and hydrodynamic controls.

Regional maps and sections showing sediment facies distribution and thickness, structural features-water salinity distribution in major aquifer systems, and temperature distribution areally and with depth were presented. Major buried delta systems describe reservoir rock occurrence; structural features define hydrodynamic controls; salinity and composition of formation waters describe chemical and physical properties of the fluid to be displaced by waste; and isogeothermal maps indicate natural flow paths and enenable calculation of density and viscosity of reservoir fluids reaction rates and equilibria, and diffusion potentials.

A-4

Waste emplacement, Southeast New Mexico

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

This project has as its objective the geologic evaluation of the thick sequence of evaporites in the New Mexico part of the Delaware Basin as a potential site or sites for the construction of a Pilot Plant Repository for radioactive wastes. The Salado Formation, the main salt-bearing unit of the area, ranges in thickness from about 1,000 feet to 1,900 feet. The formation is characterized by thick persistent units of rock salt alternating with thinner units of anhydrite, polyhalite, sylvite, and other potash minerals. Near the Eddy-Lea County line east of Carlsbad, the Salado lies at a depth of about 1,000 feet. The formation in this area exhibits only minor structural deformation.

The several exploratory boreholes to be put down in the area will provide samples for detailed lithologic and mineralogic investigations. In addition, the holes will be subjected to intensive hydrologic tests in order to determine the ground-water conditions of the area.

A-5

Snake River Plain, Part B - Volcanic Rocks

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

The purpose of the project is to geologically map, at scales of 1:250,000 and larger, the volcanic rocks of the eastern Snake River Plain and its margins. Major scientific objectives are to delineate the late Cenozoic volcanic and tectonic history in detail, to locate eruptive centers for basalt flows and for rhyolite ash-flow tuffs in relation to major structures, Quaternary faults, and geothermal areas, and to determine petrogenesis of the rocks. From the basic geologic data, derivative maps will be prepared showing potential earthquake and volcanic hazards, geothermal energy potential, construction materials and mineral resources, environmental aspects of trace element distribution, aquifers and liquid waste disposal sites, potential recreation areas, and other topics needed for land-use planning.

A-6

Water in the Elizabethtown, Kentucky, area - A Limestone Terrane Study

Performing Organization

U. S. Department of the Interior
Geological Survey
Louisville, Kentucky

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$30,000

Summary of Project -

The future economic growth of the Elizabethtown area depends in part upon the availability of reliable sources of water and on a sound program of development of these sources. Massive limestone beds having solutionally enlarged openings along bedding planes and joints are the principal source of water for public, industrial, and rural water supply. These same cavernous limestones are utilized also for subsurface disposal of domestic sewage in rural areas, drainage of storm-water runoff in urban areas, and perhaps for some industrial wastes. The several uses are in conflict with one another.

To provide detailed information on the quantity and quality of the available water in the area and to understand thoroughly the occurrence and movement of water in the limestone karst so as to guide management decisions regarding the conflicting uses of the karst.

Rainfall, runoff, evaporation, ground water, and geologic data will be collected to determine the influence of the karst on the disposition of water. Geologic-structure maps and piezometric maps will be prepared to define ground water divides and areas of recharge and discharge. Partial-record stations will be maintained on tributary streams for correlation and the flow of all large springs will be gaged periodically. Chemical and organic quality of streams and ground water will be determined.

Inventory of wells was continued in Hardin County and additional new drilled wells were inventoried in Larue County. Pumping tests were made on eight wells to determine yield and specific capacity. Discharge measurements were made on springs and streams. A seepage run was completed on Middle Creek. A seismic survey was made in areas of thick sand cover, but proved unsuccessful. Water samples were collected for analysis. The preparation of illustrations was begun.

Complete the inventory of wells in Elizabethtown and Cecilia quadrangles. Continue measurements of discharge of streams and springs and the collection of water samples. Finish seepage run on several streams. Continue pumping tests of wells where available. Begin preparation of reports.

A-7

Hydrologic effects of injecting treated sewage into deep-lying aquifers, Dade County

Performing Organization

U. S. Department of the Interior
Geological Survey
Miami, Florida 33130

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

An urgent waste disposal problem exists in south Florida. In order to alleviate the growing problem of contamination of fresh and estuarine waters, alternatives to the discharge of municipal and industrial wastes to canals, streams, lakes, and estuaries are required. Cessation of all waste discharges to inland water bodies in Dade County by 1973 was proposed by a federal-state enforcement conference. One alternative is the utilization of deep saline aquifers as a receptacle for treated sewage effluent such as is in operation near Miami, Florida.

To evaluate the potential use of deep aquifers underlying Dade County as a waste-management option for the storage, possible supplementary treatment, and ultimate disposal of treated sewage effluent.

Determination of the characteristics and behavior of the deep aquifer system and the hydrologic and geochemical effects of large-scale injection of treated sewage effluent to the aquifer system will necessitate the drilling and testing of a minimum of three observation-monitor wells, one to a depth of approximately 1,700 feet and two to 3,400 feet (drilling cost not included in program). Hydrologic, geologic, and geochemical information will be collected during drilling and after completion. Aquifer performance tests will be made and a monitor system will be established.

Reconnaissance of proposed sites for deep-well injection. Samples of surface water and ground water were analyzed to assess environmental effects of construction and testing.

Collect and analyze geologic, geochemical and biological data during drilling of deep monitoring wells.

A-8

Subsurface waste storage, statewide (hydrologic and geochemical aspects)

Performing Organization

U. S. Department of the Interior
Geological Survey
Tallahassee, Florida

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$122,500

Summary of Project -

Liquid wastes are now being injected into saline water in the deeper zones of the Floridan aquifer with indication of expanded use of the aquifer waste-storage capacity, especially in regard to storing-disposing of secondary treated sewage effluent. The hydrologic and geochemical characteristics are not adequately known to effectively evaluate the potentialities and possible consequences of subsurface waste storage. Based on the present state of knowledge, reliable prediction of the movement, chemical interactions, and ultimate fate of liquid wastes underground is uncertain.

To provide the needed scientific information base and guidelines for a comprehensive evaluation of the lithology, hydrology and geochemistry of the deep saline parts of the aquifer systems, and for planning-management decisions among a multiplicity of possible uses of the saline aquifers, including subsurface liquid waste storage. The investigation is coordinated with the geologic research phase being conducted by the Florida Bureau of Geology.

Assessment and synthesis of available hydrologic and geochemical data into a regional appraisal of the deep saline-water part of the aquifer system; inventory, assessment and evaluation of active and planned subsurface waste disposal systems in Florida, compilation of data, field investigations and preparation of summary report including case studies, and establishment of a foundation for expanded effort in subsequent years via liaison with regulatory agencies, consultants, companies, the Florida Bureau of Geology and WRD research personnel.

Field investigations, encompassing hydraulic, geochemical and geophysical technical coordination with state regulatory agencies in regard to planning, evaluation, and monitoring of waste injection systems. Continuation of hydraulic, geochemical, and geophysical studies, including comprehensive evaluation and monitoring programs at active and planned injection systems to assess environmental impact. Drilling of test wells and evaluation of the systems' response to waste injection on a regional basis in northwest Florida. Continue regional appraisals statewide. Completion of several short reports emphasizing hydrochemical studies and establishment of a scientific data base to permit development of technical guidelines for management.

A-9

Hydrology of Nevada test site

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$368,000

Summary of Project -

Hydrologic data at Nevada test site and vicinity are needed by the Atomic Energy Commission (NVOO), the laboratories, and other test-site users for programming nuclear weapons tests. These data also are necessary to assess the hydrologic safety around nuclear explosions. A) To determine ground-water recharge, storage, movement, and discharge at Nevada test site and vicinity. B) To assist in selection of sites for exploratory and emplacement drill holes. C) To determine water yields of specific rock units or intervals in drill holes, especially those intervals suitable for construction of chambers. D) To evaluate and predict ground-water anomalies produced by nuclear explosions. E) To determine rate and direction of ground-water movement by studying the relationship between geology and hydrochemistry. F) To evaluate water-supply wells at NTS and assist in selection of sites for new water-supply wells.

Hydraulic tests are made in deep drilled holes to determine ground-water quality, flow patterns, and rock permeabilities.

Selected wells are monitored periodically. Maps and overlays showing water-level contours, and wells and their construction, are updated several times each year. Preliminary equations based on available data and methods of statistical analysis, have been generated to predict the magnitude of anomalous water level around a given nuclear explosion. Changes of water quality with time are monitored. Kinetic and equilibrium data from the two-phase reaction system (rock-water) are used to evaluate transit paths and times. Production tests are made in water-supply wells.

Reports have been published on hydrology of NTS, geohydrology of Pahute Mesa, and water inflow to mined chambers. Evaluation of NTS for disposal of radioactive wastes has been initiated. Pumping and sampling of test well 400 feet from Bilby nuclear explosion is underway.

Continue programs of well testing and monitoring, updating hydrologic maps, testing and sampling water-supply wells, and studying rock/water chemical interactions. Initiate hydrologic studies in unsaturated zone beneath NTS. Initiate intensive studies of close-in hydrologic effects of nuclear explosions. Continue studies of aquifer characteristics and ground-water movement by tracer techniques.

A-10

The effect of geologic structure on the occurrence of fresh ground water in post-Oligocene deposits of the Gulf Coastal Plain.

Performing Organization

U. S. Department of the Interior
Geological Survey
St. Louis, Missouri

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$40,850

Summary of Project -

Very large rates of fluid withdrawal from Gulf Coast aquifers and petroleum reservoirs (more than 8 billion GPD of fresh water, many millions of GPD of salty water, several million barrels per day of petroleum, and enormous volumes of natural gas) have resulted in widespread large-scale head decline, aquifer water salinity changes, land subsidence, and reactivation of fault zones. Effects of oil field and industrial waste water disposal through injection wells are unknown. Superheated, overpressured, low-salinity water in regional aquifer systems freshening progressively with depth below 12,000 feet is an untapped resource needing intensive study.

To identify, describe, analyze and interpret the major structural features of post-Oligocene deposits of the Gulf Coastal Plain as they relate to the occurrence and movement of fresh ground water. Identification and description of the structural features will be based on maps showing faults with displacement greater than 100 feet and the altitude of marker beds. Analysis and interpretation of aquifer systems will explain the relation of salinity and composition of aquifer waters and the geothermal regime to the sediment facies distribution and geologic structure.

Structural and sediment facies distribution maps will be made using data provided by oil companies, supported by geophysical log cross section. Salinity and composition of aquifer waters will be mapped using chemical analyses of produced waters and electric log-derived salinity data. Isogeothermal maps will be based upon bottom-hole temperature data recorded on geophysical log headings. Computer processing of salinity, temperature, and sediment facies data will speed map preparation and the analysis and interpretation of the hydrology of the deposits.

Data collection, from oil company records, is still the major effort. Compilation, analysis, and mapping of formation-water salinity and temperature, and computer processing of data have resulted in development of new concepts on deep sedimentary basin hydrology. These, together with the basic data going into computer storage, greatly improve our capability to appraise saline ground-water resources, subsurface environments for waste storage, and geothermal resources.

A-11

Regional hydrology of the Eocene Wilcox Formation, with reference to requirements for safe disposal of liquid wastes in Gulf Coastal Plain

Performing Organization

U. S. Department of the Interior
Geological Survey
St. Louis, Missouri

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$78,000

Summary of Project -

A very large and rapidly growing chemical-petrochemical industry, and associated population, produces a wide variety of liquid wastes now generally discharged to the nearest stream or estuary. Pollution abatement and control require alternative waste handling procedures. Subsurface storage has proven satisfactory in many places, and more than 100 disposal wells are now in use in this area. Public waste-management agencies and industries faced with restrictive orders need information on the geology and hydrology as a basis for appraisal of the possibilities for local underground storage.

To develop knowledge and understanding of subsurface environments of the Gulf Coastal Plain necessary for appraisal of their suitability for liquid waste storage; to utilize for this purpose the very large store of information in oil company files; and to analyze and interpret data obtained using new concepts and principles of sedimentary basin hydrology, to make semi-quantitative determinations of the physical characteristics and geometry of reservoir rocks, the chemistry of interstitial water, and hydrodynamic controls.

Regional maps and sections will show sediment facies distribution and thickness, structural features, water salinity distribution in major aquifer systems, and temperature distribution areally and with depth. Major buried delta systems describe reservoir rock occurrence; structural features define hydrodynamic controls; salinity and composition of formation waters describe chemical and physical properties of the fluid to be displaced by waste; and isogeothermal maps indicate natural flow paths and enable calculation of density and viscosity of reservoir fluids, chemical reaction rates and equilibria, and diffusion potentials.

Collection of geologic and formation-water salinity data is more than half completed; arrangements for purchase of structural data are in progress. Several thousand geophysical logs for studies of sediment facies distribution and isogeothermal mapping have been obtained. Preliminary study of sediment facies and water salinity distribution indicates that salinity is greatest in alluvial and upper deltaic channel sands and progressively decreases towards marine margins of deltaic sequences.

A-12

Hydrology of Basalt and other rocks underlying Hanford AEC site, Richland, Washington

Performing Organization

U. S. Department of the Interior
Geological Survey
Richland, Washington

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$58,000

Summary of Project -

Large quantities of high-level radioactive wastes are stored in below-ground tanks at the Hanford works reservation of the U. S. Atomic Energy Commission near Richland, Washington. To more effectively isolate the wastes from the biosphere, the Atomic Energy Commission is considering emplacing the wastes in chambers to be excavated at depths of about 3,000 to 4,500 feet in the basaltic rocks underlying the reservation. The long-range environmental safety with regard to migration through the ground-water system of radionuclides from the proposed storage chambers is a principal concern.

The investigation is aimed at the prediction of the direction and rate of movement through the ground-water system of any long-lived radioisotopes that may leave the proposed storage chambers. Such prediction requires knowledge of (1) The hydrologic and hydraulic characteristics of the ground-water system and any modifications of the system resulting from future development of ground water and surface water in the region, and (2) chemical interactions among the wastes, ground-water, and rocks.

Field investigations to obtain the parameters necessary for defining the ground-water flow system consists of (1) measurement of heads at different points in the system, (2) hydraulic tests of discrete water-bearing zones to determine values of hydraulic conductivity and specific storage, (3) collection of rock samples for laboratory determination of hydraulic and physical properties and mineralogy, (4) collection of water samples for determination of chemical and isotopic constituents, and (5) geophysical logging of wells. Much of this information will be obtained from about seven proposed test wells, 4,000 to 6,000 feet deep, and several deep core holes within the Hanford reservation. Studies will be extended to the surrounding area by collecting hydraulic data samples from existing wells. Mathematical models will be developed of the ground water and geochemical systems.

Interpretation of geophysical logging, hydraulic, and chemical data from the first deep test well ARH-DC-1 (5,661 ft, in depth) was completed and an open-file report was prepared. Hydrologic conditions appeared favorable enough to warrant further exploration. A reconnaissance was made of the entire area of study to select about 25 water wells, which were then sampled. (Text abridged)

A-13

Investigation of the use of deep wells for waste disposal near Pensacola, Florida

Performing Organization

U. S. Department of the Interior
Geological Survey
Ocala, Florida 32670

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$10,000

Summary of Project -

Two deep wells are presently being used to inject organic industrial wastes into a saline limestone aquifer near Pensacola, Florida. There are indications that larger quantities of waste will be injected and that wells for this purpose may be constructed by other industries. Unless properly evaluated fresh water aquifers could be contaminated and irrevocable damage could result.

Disposal of wastes underground presents many potential problems which require evaluation in order to safeguard the public and in order to better understand the physical and chemical processes involved. This project will provide the means to evaluate some of the hydrologic and geochemical effects of acidic industrial wastes on a limestone aquifer, a clay aquiclude, and overlying aquifers. It may form a basis for similar studies in other areas and a basis for decisions relative to deep well waste disposal.

Chemical, physical, and hydrologic data collected from the operation of two industrial waste disposal wells are analysed and evaluated. Aquifer tests are conducted to study aquifer characteristics. Monitor wells are used to record pressures in the receiving formation and the aquifer above the confining layer. Water samples from monitor wells and samples of the industrial waste are analysed periodically. Geologic samples from the injection horizon and confining layer are analysed and controlled experiments are conducted to study limestone solution rates in the acidic waste at aquifer pressure and temperature. Theoretical potentiometric surface maps are constructed to depict present and future hydrologic conditions.

Injection of chemical waste into a confined limestone aquifer in Pensacola.

Continuous pressure recorders will be operated and maintained on all monitor wells. Water samples from all monitor wells will be analysed monthly for pH, alkalinity, temperature, boron, the nitrogen species, calcium, magnesium, specific conductance and total organic carbon. Semi-annual samples will be analysed for boron, copper, iron, zinc, and standard constituents. A 8-10 backflushing experiment will be conducted at one of the injection wells.

A-14

Hydrogeology of the Wilcox group (Eocene), Texas -- A regional appraisal with reference to storage of fluid wastes in the subsurface

Performing Organization

U. S. Department of the Interior
Geological Survey
Bay Saint Louis, Mississippi

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Very large and rapidly growing chemical-petrochemical complexes, industry, manufacturing, and the associated population, produce a wide variety of fluid wastes which are generally discharged to the nearest stream or estuary. Pollution abatement and control require alternative waste-handling procedures. Subsurface storage has proven satisfactory in many places, and more than 100 waste-injection wells are now in use in this area. Public waste-management agencies and industries faced with restrictive orders need information on the geology and hydrology as a basis for appraisal of the possibilities of underground storage as an alternative waste-handling procedure.

To develop knowledge and understanding of the deep subsurface environments of the Gulf Coastal Plain requisite for appraisal of their suitability for storage of liquid wastes; to utilize for this purpose the very large store of information in oil company files; to analyze and interpret data obtained using new concepts and principles of deep basin hydrology; to make quantitative and semi-quantitative determinations of the physical properties of reservoir rocks, the chemistry of interstitial waters, and hydrodynamic controls; and to demonstrate how deep aquifers can be described so that local site requirements for waste injection can be related to the regional hydrology.

Work will be accomplished in two (2) phases. Phase 1 will describe the geologic framework of the Wilcox group between the Rio Grande and the Sabine River. Regional maps and sections will show the distribution and thickness of sedimentary systems and their component facies and phases and structural features. Phase 2 will describe salinity distribution and geothermal conditions in the entire Wilcox group and aquifer characteristics, head distribution, and formation water composition in the Rockdale Delta system (lower Wilcox) between the San Marcos Arch and the Sabine River.

A-15

Effects of disposal wells on water quality, Western Snake Plain Aquifer, Idaho

Performing Organization

U. S. Department of the Interior
Geological Survey
Boise, Idaho 83702

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

There are thousands of disposal wells used to inject surplus runoff, irrigation water, effluent from septic tanks, industrial wastes, and runoff from streets into the Snake Plain aquifer of southeastern Idaho. There is concern by many people and agencies that the use of disposal wells is directly polluting or contaminating the aquifer. There is, therefore, need for a study which will provide information on the quantity and quality of water being injected into the aquifer and its effect on groundwater quality. The information is needed as a basis for establishing water quality standards and design criteria for disposal wells.

Gooding, Jerome, Lincoln, and Minidoka counties were selected as being representative of the basalts of the Snake Plain aquifer. Data to be collected will be indicative of the rates, quantity, and quality of water now being injected into the aquifer by disposal wells. These data are to be interpreted to show the local and regional effects of drain wells injecting different types of water into the Snake Plain aquifer. Overall effect of drain wells on ground water quality is to be compared to the effects of deep percolating irrigation water, canal leakage, and drainage from septic leach lines.

The flow into a representative number of disposal wells will be analyzed for common ions, nutrients, sediment, coliforms, and streptococci. Estimates of total quantities of water and chemical loads being injected will be based on measured inflow rates, irrigated acreages, evapo-transpiration, precipitation, quantities of water pumped or diverted, published data on sewage, census data, and chemical analyses of the injected waters. Decay rates and chemical interactions will be considered. An attempt will be made to document cases of drain well induced contamination, or deterioration of water quality in ground water.

A-16

Feasibility of Eastern Triassic Troughs for subsurface storage of liquid wastes

Performing Organization

U. S. Department of the Interior
Geological Survey
Raleigh, North Carolina

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Recent regulation of the disposal of toxic wastes necessitates the search for storage sites remote from man's normal and anticipated activities where these wastes can degrade. Places in the upper few miles of the earth's crust are currently being used for storage where the rocks, minerals, or pore fluids involved are unusable or their extraction uneconomical by today's technology. The Triassic Troughs of eastern U. S. are possible sites for waste storage because of their structure entity, saline water content at depth, and proximity to industrial centers and because of the permeability contrast of sediments.

To gather and compile data on the geologic architecture of the east coast Triassic Basins, the geometry and physical character of their contained sedimentary and igneous rocks, and the chemistry and physical nature of their contained fluids. These geohydrologic data will be used to develop criteria for the ultimate selection or rejection of individual Triassic Basins as sites for storage of various liquid wastes.

The first year's work consisted of review of the pertinent Triassic literature, compilation of available hydrologic and geologic data, preparation of an administrative report containing available geologic, hydrologic, and water quality data on each basin, and recommendations. Effort in the second and third years will concentrate on field investigations designed to recover those subsurface data which the literature search has indicated to be especially pertinent to the disposal problem but unavailable from existing data files.

A-17

Performing Organization

U. S. Department of the Interior
Geological Survey
Tampa, Florida

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$52,000

Summary of Project -

Pinellas County is seeking a means of ultimate disposal for secondary effluents within the county other than disposal into the warm shallow bays of its prime beach area. The gulf is very shallow in this area and ocean outfalls would need to be 20-30 miles out.

To determine if isolated saline water zones exist capable of accepting large quantities of waste water that could be used for waste disposal without endangering the fresh water supply.

Wells will be drilled and cased to various depths. Wells penetrating and cased to a particular zone will be pumped and wells penetrating and cased to other zones will be observed to determine the degree of interconnection between zones within the aquifer. Injection tests using fresh water will be conducted to determine the rates a particular zone will accept water.

Batteries of wells were installed at the spray irrigation site and adjacent area. Wells in each battery range in depth from 5-40 feet. Soil samples were collected while drilling the wells and analyzed for permeability, ion exchange capacity and base saturation.

To commence drilling wells for deep injection.

A-18

Geologic and hydrologic factors relating to subsurface waste disposal in Kentucky

Performing Organization

U. S. Department of the Interior
Geological Survey
Louisville, Kentucky

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$27,000

Summary of Project -

Increased interest in subsurface disposal of wastes in the past few years has resulted from stricter regulations controlling release of liquid wastes into surface streams and improvements in waste treatment processes which produce more concentrated wastes. The increasing interest on the part of industry has resulted in several applications for permits for underground waste disposal to regulatory agencies in Kentucky. The agencies have been hampered in exercising this responsibility by lack of data on the character of potential disposal zones, and on possible effects of underground disposal on natural fluids and minerals.

Identify and describe permeable zones which might be considered for disposal of fluid wastes. Define location, extent, boundaries and hydraulic properties of the zones and possible hydraulic connections with other zones or fresh-water aquifers. Determine the quality of existing water and direction and velocity of water in the permeable zones. Set up a digital model or models to estimate the effects of waste disposal in these zones, if adequate data are acquired. The purpose of this study would be to provide the state of Kentucky information needed for enforcement and surveillance of subsurface water quality standards and waste-disposal practices.

The areas where the need for information is most imminent will be selected for early study. Data, mostly in files of the Oil and Gas Division of Kentucky Geological Survey, will be used to interpret permeable strata or zones, generalized state-wide geologic structure and permeability, chemical constitutents, and potentiometric surfaces of the various permeable zones. Data on adjacent low permeability zones will also be noted. Preparation of a digital computer model to simulate the hydrology of disposal zones will be attempted, data permitting. Water samples and field data on deep wells will be collected on continuing basis.

Literature has been reviewed on subsurface waste storage and on subsurface stratigraphy of Kentucky. State files have been searched for pertinent data and little has been found. Report writing has begun on a generalized report on subsurface waste storage possibilities in the various physiographic regions in Kentucky.

A-19

Isotope geochemistry of deep saline and fresh water aquifers of Atlantic Coastal Plain, with reference to liquid waste storage (Abbrev)

Performing Organization

U. S. Department of the Interior
Geological Survey
Arlington, Virginia 22209

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$103,635

Summary of Project -

Disposal of industrial liquid wastes to deep saline aquifers is increasingly being used by industry to partially satisfy the demands for a clean environment. Yet, such injection, when hastily undertaken, may pollute overlying fresh ground water supplies or brackish waters suitable for de-salination. The greatest potential for subsurface storage is in deep saline aquifers capped by extensive aquitards. Such aquifers underlie portions of the Atlantic Coastal Plain, but little is known about their hydrogeology or geochemistry.

The study seeks to determine the geochemistry age, and flow paths of saline water, and up-gradient fresh water, in several regional aquifers beneath the central and Northern Atlantic Coastal Plain. Such basic information is essential background for the detailed hydrogeologic and chemical engineering studies which precede selection of specific liquid waste storage sites.

Sparseness of wells tapping the deep saline aquifers beneath the coastal plain necessitates use of indirect and direct interdisciplinary approaches to study suitability of these aquifers for waste storage. Indirect approaches include: isotopic dating of fresh ground water in regional aquifers containing salt water down the hydraulic gradient; and compilation of published permeability and mineralogic data for such aquifers. Direct approaches include: study of the isotope geochemistry and hydrogeology of saline water at actual waste disposal sites; and collection of isotopic, chemical, hydraulic, and mineralogic data from deep test holes drilled during this investigation.

The bulk of the year's field work was devoted to collection of well water samples from the Raritan-Magothy-Potomac Aquifers System beneath the New Jersey Coastal Plain, and the Peedee Formation beneath the Hercules waste disposal site near Wilmington, N. C. Interpretation of flow patterns and water ages in these aquifers awaits receipt of isotopic analyses from the laboratories. The potential utility of selected thick unsaturated zones in the Southwest as storage sites for solidified high-level radioactive wastes is discussed in a report currently in review (HPI). The assets and liabilities of this neglected, but important environment, are detailed and contrasted with those of other commonly proposed storage or disposal environments.

A-20

Evaluation of feasibility of deep-well waste disposal in Western New York and prediction of reaction of aquifer system to applied stresses

Performing Organization

U. S. Department of the Interior
Geological Survey
Albany, New York

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$30,000

Summary of Project -

The use of underground space as a disposal zone for industrial and municipal waste is currently being considered in New York. The state regulating agency is in accord with the concepts of regional management of deep-well injection as described in USGS Circular 621 by A. M. Piper. In order to adequately develop guidelines for such regional management in Western New York State, it is necessary to understand the hydrology and geology of the injection formations and develop a prediction capability for the consequences of injection. A deep well to inject acid pickling liquor is ready to go on-line during 1972. Pumping tests indicate that the injection formations will not easily accept large volume of waste.

Short-term - to provide understanding of the hydrology of injected formations and its relationship to stratigraphy; to evaluate waste reaction with the formation and its fluids. To provide data and insights to improve regulatory arrangements for operation of the injection well. Long-term - to provide insights for regional management of deep-well injection in Western New York; to evaluate the practicality of computer simulation of hydrologic and geochemical changes resulting from deep-well injection processes; to evaluate the state of knowledge concerning reaction between extremely acid wastes with high iron concentrations and carbonate rock.

The Potsdam Sandstone and Theresa Formation of Western New York will be studied to evaluate the areal extent of carbonate and sandstone strata. Petrologic examination of samples will determine physical characteristics including porosity and permeability. The geochemical interaction between acid waste, dolostone of the injected formations and native saturated brines will be studied. A combination of well test data, stratigraphy, and model simulation will be used to predict the effects of injection. Existing computer programming may be adapted to accommodate the variables of the injection formations; the resulting model simulation will help in predicting hydrologic changes in this environment.

A-21

Geochemical aspects of ground-water pollution in the Babylon-Islip Area, Long Island, New York

Performing Organization

U. S. Department of the Interior
Geological Survey
Mineola, New York

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$56,000

Summary of Project -

Ground-water and, to some extent, surface water in the Babylon-Islip area, Long Island, New York, have been polluted by the activities of man. The source of public water supply in the area is ground-water derived from the upper glacial and magothy aquifers. The extent and manner of pollution in the two aquifers needs to be more clearly defined so as to provide a basis from which water managers can develop plans to assure a safe public water supply in the future along with satisfactory disposal of sewage and waste materials without attendant deleterious effect to the ecology or the environment.

The major objective of this proposed project is to evaluate the geochemical aspects of the nature, extent, movement, and temporal variants of inorganic and certain organic pollutants in the ground-water reservoir of the study area, with special emphasis on the water in the upper glacial and magothy aquifers. The information thus developed will be useful in evaluating present and future suitability of ground-water for public use, and will provide a data base and data collection network for monitoring the effects of proposed sewers. Other water-management activities, and waste disposal.

Assemble and review existing hydrologic data and reports on the area of study. Collection of new data will consist of: Periodic water-level measurements; collection of water samples from existing wells and streams. Additional wells will be drilled in areas where needed; especially in the vicinity of sanitary landfill and sewage disposal operations. Stage and conductivity records will be installed on streams or wells where needed. A series of maps and cross sections will be constructed to show areal and vertical extent of pollutants in the aquifer as well as temporal trends.

A ground-water and surface water sampling network has been established and samples collected for chemical analyses including the toxic-trace metals. The chemical data has been placed on maps for contouring water-quality parameters. 5,000 chemical analyses from cooperator's files have been processed for computer analyses of trends in water-quality changes. Water levels are being measured for preparation of water level change maps.

A-22

Mathematical modeling of waste transport and dispersion in the Snake River Plain Aquifer, National Reactor Testing Station, Idaho

Performing Organization

U. S. Department of the Interior
Geological Survey
Idaho Falls, Idaho 83401

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Liquid chemical and radioactive wastes have been discharged to the Snake River Plain aquifer at the National Reactor Testing Station, Idaho, since 1952. The aquifer is the largest and most productive ground water resource in Idaho. As the wastes are carried downgradient, their distribution and behavior is controlled by a complex combination of hydraulic, dispersive, chemical, and radioactive influences. In order to understand the observed behavior of the wastes and to predict future effects of the wastes on the valuable aquifer, a digital model is needed to simulate the complex processes operating on the waste-aquifer system.

To develop a digital computer mathematical model which will simulate the Snake River Plain aquifer system in the NRTS vicinity and the significant processes controlling the transport of NRTS waste products in the aquifer, such as dispersion, radioactive decay, and sorption. The first objective will be to adequately simulate the observed waste behavior patterns from 1952 through 1972. When the model does that satisfactorily, it will then be used to predict future waste distribution patterns under a variety of assumed future disposal schemes.

Two coupled phases of modeling are involved. The first is to adapt an iterative alternating-direction implicit numerical model for the flow of ground water in the aquifer. The second is a digital model for the dispersion and chemical controls on the waste transport. This utilizes the recently developed method of characteristics for the solution of the differential equations of transport. The chemistry model depends upon velocity vectors generated by the hydrology model.

Basic background data was compiled, and analyzed. After completion of a two-week course in digital modeling techniques, a preliminary digital model of the ground hydrology of the NRTS vicinity was successfully completed. With help of other USGS experts, a preliminary digital waste transport model was completed and coupled with the hydrologic model. The transport model includes the effects of dispersion and radioactive decay and has satisfactorily simulated the behavior of the Idaho chemical processing plant's waste chloride and tritium in the Snake River Plain aquifer from 1952 to 1970. Predictive simulations were also made up through the year 1983.

The transport model will be refined and expanded so that longer-term predictions can be made.

A-23

Feasibility of the injection of liquid acid wastes in the Theresa and Potsdam Formations of Western New York

Performing Organization

State Department of Education
B. Swan, New York State Office Bldg.
Albany, New York

Supporting Agency

New York State Government

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

To describe the geochemistry of the Theresa and Potsdam Formations in Western New York, their permeability and porosity and the hydrology of natural brine fluids existing within the formation. This information will be evaluated together with expected chemical reactions between acid waste and dolostone rock of the Theresa Formation. The hydrologic model which is developed for the Theresa and

Potsdam Formations, will be used to predict the pressure effects of deep well injection. The probability of earthquake activity associated with injection will also be explored.

In cooperation with the United States Geological Survey, a hydrologic modeling investigation of the Theresa and Potsdam Formations has been undertaken. Sedimentary petrology of the Theresa and Potsdam Formations is also under investigation. Natural earthquake activity is being monitored in Western New York in cooperation with Lamont-Doherty Geological Observatory.

Current plans and/or progress includes the development of a computer model simulation of the hydrologic characteristics of the Theresa and Potsdam Formations in Western New York. Geochemical evaluations of the dolostone associated with the Theresa Formation are in progress and laboratory evaluations of chemical reactions between highly acid pickling liquor waste and Theresa dolostone are in progress. Plans for the development of an experimental well have been delayed by lack of funding.

A-24

Sedimentary petrology of the Theresa and Potsdam Formation

Performing Organization

State Department of Education
S. Swan, New York State Office Bldg.
Albany, New York

Supporting Agency

No formal support reported

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

To investigate the textures, mineralogy, and sedimentary structures of the Theresa and Potsdam Formation in order to understand the environment of deposition.

Porosity and permeability information is being derived from study of drill core and from gamma-gamma log records of wells drilled through these formations.

This project is integrated with the evaluation of the geologic feasibility of injection of acid liquid wastes into the Theresa and Potsdam Formation in Eastern New York.

A-25

Deep well injection of non-reclaimable liquid wastes

Performing Organization

State Department of Water Resources
Los Angeles, California 90055

Supporting Agency

California State Government

Period	Man Hours	Funds
10/72 to 6/73	N/A	$21,000

Summary of Project -

The objective is to assess the potential for deep well injection of non-reclaimable liquid wastes compatible with the surrounding environment. The three phase program consists of review of existing injection technology and costs; location of areas of potential storage; and evaluation of alternative waste disposal methods.

A-26

Geology of the Boulder Zone

Performing Organization

State Bureau of Geology
P. O. Drawer 631
Tallahassee, Florida 32302

Supporting Agency

Florida State Government
(Multiple Support)

Summary of Project -

Approximately along the contact of the fresh water with the salt water of the Floridan artesian aquifer there occurs an extremely pervious zone which the well drillers have called the "Boulder Zone". This zone apparently represents some subsurface formation that has been easily dissolved and has been removed, or it represents a solution zone that has formed along the contact of fresh and salt water in the artesian system. The dynamics of this flow are not fully understood and it is hoped that further study of the zone, both the hydrology and the geology will provide sufficient knowledge to allow its safe usage for storage of fresh water in the distal end of Florida where the artesian water is brackish or to use this zone for waste disposal after the waste has been treated to some extent and reduced to sludges.

A-27

Investigation of permeability of fine grained glacial sediments in relation to waste disposal in Illinois

Performing Organization

State Geological Survey
Urbana, Illinois 61801

Supporting Agency

Illinois State Government

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

The objective of the research is to evaluate current methods and to develop practical procedures for determining the field permeability of fine-grained glacial sediments. These sediments - mainly tills - are too tight to be analyzed for permeability on the basis of conventional pumping tests. Field measurements of permeability in shallow bore holes are being made utilizing a number of techniques, including long-term injection tests. Laboratory tests, made on cores by standard permeameter methods, are to be made for comparison to field data.

The permeability data will be obtained from representative glacial deposits of known character and extent, so that results may be extrapolated, and will be evaluated for such practical applications as selecting sites for surface waste disposal, protecting shallow aquifers from pollution, and appraising drainage and ground water recharge conditions.

A-28

Pilot scale investigations of well recharge using cored samples

Performing Organization

State Water Survey
Box 232
Urbana, Illinois 61801

Supporting Agency

Illinois State Government

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Purpose of this study is to determine the feasibility of recharging treated sewage effluent into the Cambrian-Ordovician (deep sandstone) aquifer in Northeastern Illinois.

The physical, chemical, and biological factors affecting rates at which the effluent can be injected into the aquifer are being investigated. The effectiveness of the filtering action of the aquifer is being studied. Methods of further treatment of secondary or tertiary treated sewage effluent are being investigated so that effluent can be successfully used to recharge the aquifer system. Some success was had in maintaining constant recharge rates at constand heads through sandstone cores.

One objective of further study will be to maintain constant recharge rates for longer periods of time.

A-29

Study of transient mass transport around liquid waste injection wells in Illinois

Performing Organization

University of Illinois
Water Resources Center
Urbana, Illinois 61801

Supporting Agency

Illinois State Government

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

The objectives of this study are to investigate the development of pressure buildup around an injection well in Illinois in an aquifer with density stratification, and use this result to predict the movement of the injected fluid with a different density than the native water in the aquifer. It is planned to arrive at these objectives by the use of numerical solution by laboratory and field tests.

The success of the numerical solution is directly related to the validity of the mathematical models. This means that the models must incorporate lateral and longitudinal variations in permeability, density, diffusion, coefficient, and other related parameters. Once such models are developed, some newly developed solution techniques such as finite element or Galerkin technique, subject to proper boundary conditions, will be employed for their solutions. Some theoretical assumptions that will be incorporated in the mathematical models will be checked by the use of laboratory models and, if possible, by the field data.

A-10

Subsurface liquid waste disposal

Performing Organization

State Water Survey
Box 332
Urbana, Illinois 61801

Supporting Agency

Illinois State Government

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

In cooperation with the State Geological Survey, a study has begun of the flow and mass transport phenomena involved in liquid waste disposal by injection into deep Illinois aquifers. The purpose is to devise methods of predicting the pressure distribution and the movement of waste fluid in the vicinity of an injection well. The resulting information should prove useful in formulating operating conditions for disposal wells which will minimize the possibilities of polluting water-supply aquifers.

The present cooperative work is aimed at comparing alternative techniques for the numerical solution of the mathematical equations describing fluid flow and mass transport through an aquifer, in an effort to devise an efficient computer model for simulating waste injection systems. Subsequent work will involve the determination of appropriate values for the parameters involved in the computer model, and then the application of the model to the simulation of actual waste injection.

A-11

Surficial materials of the Salem Plateau

Performing Organization

State Geological Survey & Water Resources
Rolla, Missouri 65401

Supporting Agency

Missouri State Government

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

Basic purpose is to map surficial materials, but observations relative to various aspects of waste disposal effects on possibilities of ground water pollution will be made.

A-12

Subsurface liquid waste disposal and its feasibility in Pennsylvania

Performing Organization

Geoengineering Labs., Inc.
P.O. Box 781
Mount Vernon, Illinois

Supporting Agency

Pennsylvania State Government

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

To provide: (1) a comprehensive review of the principles involved in subsurface liquid-waste disposal and possible effects upon the rock/fluid system; (2) a review of available techniques for site selection, control, and monitoring; and (3) a study of the regional geology of Pennsylvania drawing attention to factors favoring or inhibiting the development of disposal facilities. The study is intended primarily to provide a background for non-geological personnel concerned with liquid-waste-disposal operations.

The study was based on extensive review of pertinent literature, investigation of governmental and industrial records, and conventional sources of regional geological information.

A-11

Bedrock waste storage exploration

Performing Organization

U. S. Department of the Interior
Geological Survey
Columbia, South Carolina 29204

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Summary of Project -

One proposal for the permanent containment of highly radioactive waste at the Savannah River Plant is to store it in a chamber excavated in crystalline basement rock which is buried beneath 1,000 feet of coastal plain sediments. The natural movement of ground water is the most significant driving force that might cause the migration of waste from the chamber. The objective of this project is to determine the movement and possible movement of ground water through the small fractures in the crystalline rock and in the sediments above as it relates to waste containment.

A previous study provided an evaluation of the hydrology of crystalline rock in the immediate vicinity of the proposed storage chamber. A second previous study explored the hydrologic characteristics of the region. Based in part on the two previous studies AEC has proposed to sink an exploratory shaft through the coastal plain sediment and into the rock, and to excavate a smaller diameter but full length exploratory tunnel. In addition, some further exploratory work is proposed to precede and complement the exploratory shaft and tunnel. This USGS project includes: (1) geohydrologic consulting advice to AEC in their further deliberations on underground waste management and in investigative program formulation, and (2) to extend and refine some of the geohydrologic interpretations developed in the two previous studies.

Previous studies indicated that the permeability of the buried Triassic sediment is extremely low and that the frequency of water transmitting fractures in these sediments is extremely low. Therefore, this buried Triassic basin will be further explored by seismic and test drilling methods. The hydraulic data from the one-year pumping test and the two-year tracer test can be analysed by a digital simulation of the flow system. This will be done incorporating all other hydraulic data to develop a consistent hydrologic model.

Collection and analysis of test well data and the monitoring of observation wells in the SRP site.

A-34

The shallow hydrogeologic environment of Northeastern Illinois

Performing Organization

Illinois State Geological Survey and
University of Illinois
Urbana, Illinois

Supporting Agency

Illinois State Geological Survey and
University of Illinois
Urbana, Illinois

Period	Man Hours	Funds
7/65 to 6/66	N/A	N/A

Summary of Project -

A study of the influence of topography, types, and distribution of earth materials, seasonal rainfall variation, and to some extent vegetation on the ground water potential (head) distribution. The potential distribution in the vicinity of lakes and marshes in both clays and sands and gravels is of particular interest because these areas may be useful as waste disposal sites provided it can be shown that they are permanent discharge areas and therefore that no ground water pollution hazard exists. Furthermore, if these marshes are permanent discharge areas, it is hoped that the equipotential line separating upward from downward movement in the sites studied can be located and their seasonal variations observed. Chemical content of water in the vicinity will also be determined. This information can then be projected to other areas where similar conditions exist. It is also anticipated that a basis can be established for estimating the percentage of infiltrated water that finally reaches deeper aquifers.

The necessary information was obtained primarily by piezometers, either driven or not according to the Casagrande method.

A-35

Deep well disposal

Performing Organization

Virginia Polytechnic Institute
Water Resources Research Ctr.
Burruss Hall, Blacksburg, Virginia 24061

Supporting Agency

U. S. National Science Foundation,
Division of Environmental Systems & Resources

Period	Man Hours	Funds
6/72 to 11/73	11,100	$94,300

Summary of Project -

The project is to assess how institutional economic, and physical factors enter into the use and regulation of deep well waste disposal methods in an environmentally acceptable manner. Primary emphasis will be placed on the analysis of the legal and institutional aspects of deep well waste disposal. Economic and physical considerations will be incorporated to the extent necessary for formulating policy issues and for identification of the parameters essential for effective regulation.

The project is to identify the various deep well techniques now being used, to define their physical limitations, and to examine how they can be effectively regulated, this study will: 1) analyze the laws and regulations now being used with respect to deep well waste disposal; 2) compare laws and regulations of states that have similar physical conditions; 3) explore the legal framework for the implementation of effective monitoring and control; 4) identify critical factors which determine the conditions under which deep well disposal of wastes can become a viable method. The Mid- and South-Atlantic Region is used as the focus of the case study.

BIOLOGIC STUDIES

B-1

Subsurface aeration of ground water for inducing bacterial dissimilation of phenolic pollution in basalt aquifers West of Melbourne (Abbrev)

Performing Organization

Victoria Geological Survey
Melbourne, Victoria, Australia

Supporting Agency

Victorian State Government

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

To test the effectiveness of newly developed borehole technique for beneficiating ground water polluted with high concentrations of phenolic compounds.

High concentrations of phenolic compounds have been observed in ground water occurring in a series of observation bores surrounding a quarry used for disposal of industrial effluent. The ground water occupies a shallow Basalt aquifer system which consists of an upper unconfined and a lower partly confined aquifer.

Phenol oxidising organisms are known to be present in the ground water (Millis in litt. 9/5/72). It is proposed to use special intra-well flow devices developed by Riha (1971) to induce regulated flow from the upper more polluted aquifer to the lower aquifer which is at a slightly lower head. The bore will be constructed so that there is maximum aeration of the descending water. It is anticipated that this transfer will serve two functions, both of which will tend to improve the quality of the polluted ground water: (1) Dilution by mingling with relatively unpolluted water in the lower aquifer. Over a period, water will be drawn in from less polluted parts of the upper aquifer surrounding the highly polluted phenolic zone. (2) Aeration of the descending water should promote development of the phenol-oxidising organisms already present, thus providing improved conditions for dissimilation of the phenolic pollution.

B-2

The role of microorganisms in the decomposition of deep well injected liquid industrial wastes

Performing Organization

University of North Carolina
School of Agriculture
Raleigh, North Carolina

Supporting Agency

U. S. National Science Foundation
Division of Environmental Systems & Resources

Period	Man Hours	Funds
7/73 to 6/74	N/A	$36,650

Summary of Project -

Storage and disposal of industrial chemical wastes by injection into deep aquifers is a practice in use and growing with little base of knowledge as to the biological implications of such a waste disposal system. This research is sited at an experimental deep well located in Wilmington, North Carolina designed for injection of 300,000 gallons per day of industrial waste water from production of dimethyl trephthalate into formations 850 to 1,025 feet deep. The experimental system includes an injection well and observation well being operated under a permit issued in 1968 by the State of North Carolina which included provisions for study of the feasibility and effects. Objectives of this study are to develop techniques for sampling and isolating microorganisms indigenous to deep aquifers as a necessary prerequisite to determination of changes that may occur in microbial population resulting from waste water injection. The roles of indigenous organisms in degradation of the waste constitutents and the waste water injection procedure in causing dispersal of microorganisms in the aquifer are also being studied. Innoculation of waste water constitutent degradation will be investigated to determine the feasibility of utilizing deep well systems for treatment of industrial waste waters.

B-1

Organic aspects of deep waste storage

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$90,000

Summary of Project -

The enforcement of water-quality standards for major rivers of the United States has forced many companies and municipalities into larger expenditures for sewage and waste water treatment facilities. A cheaper alternative for many companies is to dispose of certain wastes in presently unusable saline zones at various subsurface depths. Most subsurface disposal systems are constructed and operated without knowledge of the fate, reactivity, or distribution of the waste in the disposal zone. Without due consideration of hydrological, chemical, and geological factors such serious problems as contamination of fresh water aquifers, and well failures may result.

(1) To predict the reactions and interactions between certain organic wastes and aquifer components when organic wastes are placed in the subsurface. (2) To establish the organic water quality of several uncontaminated ground water aquifers of the United States. (3) To define the effects chemical and biological reactions have on the distribution and movement of organic wastes in the subsurface.

Fiscal Year 1972: An extensive literature survey on organic aspects in ground water, ground water recharge, and deep water disposal will be compiled. The naturally occurring organic content of selected aquifers of the United States will be determined by periodic sampling. Fiscal Year 1972-77: Various instrumental and experimental capabilities for surface water organic studies will be adapted and modified for organic investigations of ground water. The instrumental capabilities include gas chromatographic, electrophoretic, and mass-spectrometric techniques, as well as elemental and infrared analyses. Several reconnaissance studies of deep waste injections of organic substances will be conducted. Certain sites will be chosen for intensive studies to determine the reactivity, fate, and movement of organic waste in the subsurface.

Phase I-3 will be continued, but major emphasis will be on predicting the reactivity, fate, and movement of organic wastes in the subsurface at the Wilmington, North Carolina, disposal site. Laboratory models will be combined with field observations to attain these objectives. Manuscripts will be completed for publication. Several papers and lectures on organic waste disposal are planned.

B-4

Microbial ecology of ground water

Performing Organization

U. S. Department of the Interior
Geological Survey
345 Middlefield Road
Menlo Park, California

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$41,800

Summary of Project -

Little is known of the biota living in ground water. This project will supply information in this area.

Isolate, identify and describe biota found in ground water. Much of the effort will be directed toward the requirements of artificial recharge and underground waste disposal studies. Results should be applicable to specific problems in recharge and waste storage practice.

Bacteria and fungi will be isolated from ground water sources. Both existing wells and core material from wells under construction will be exploited as sources. In place sampling with contact slides and sand probes will be attempted. Microorganisms found will be identified and examined by standard microbiological techniques. Special biochemical features of the organisms will be studied as appropriate. This information will be used to construct ecological models.

A comprehensive review of the effects of biota on waste injection and storage was completed. Methods for determining the base composition of deoxyribonucleic acid isolated from well-clogging bacterial species were investigated. This information is useful for classifying bacteria. Simple methods, which do not involve sophisticated equipment were used. Unfortunately the data obtained by use of such simple methods was not sufficiently precise for the intended use. Since analytical ultracentrifuges, needed to perform more precise analysis, are unlikely to become available in the near future this line of investigation has been abandoned. Field tests at Bay Park, Long Island, New York, demonstrated that bacteria can be primary causes of well clogging if the injectant is not chlorinated.

Growth of bacteria under controlled condition in packed sand columns under laboratory conditions will be studied in cooperation with the Texas High Plains Recharge Study. Principles governing the growth of microbes in ground water will be investigated. Role of bacteria in solubilizing pyrite will be emphasized.

CHEMICAL STUDIES

C-1

Water conservation by waste water reclamation and injection or recharge

Performing Organization

County of Nassau
Department of Public Works
Mineola, New York 11501

Supporting Agency

Department of the Interior
Federal Water Pollution Control Administration

Period	Man Hours	Funds
1/67 to 12/67	N/A	$30,000

Summary of Project -

The purpose of this project is to conduct pilot studies on activated sludge sewage effluent to improve its quality to conform with required drinking water standards and inject or recharge it into subsurface water bearing strata for re-use after removal of suspended solids. Using all information available in this field and also data obtained from bench scale and pilot plant units, a tertiary treatment plant will be designed and constructed. In addition, an injection well and a network of observation wells will be dry and operated on a three-four year program.

C-2

Long Island recharge study

Performing Organization

New York State Department of Health
84 Holland Avenue
Albany, New York

Supporting Agency

Public Health Service and
New York State Department of Health

Period	Man Hours	Funds
1/68 to 12/68	N/A	$30,000

Summary of Project -

This study is to determine the treatment requirements for sewage reclamation for recharging into the ground waters by injection wells, and conducted at Riverhead, Long Island, utilizing the sewage from the municipal trickling filter sewage plant.

C-3

Advanced waste treatment for water reclamation and re-use by injection

Performing Organization

Nassau County Department of Public Works
Mineola, New York

Supporting Agency

Interior Department
Federal Water Quality Administration

Period	Man Hours	Funds
7/64 to 6/70	N/A	N/A

Summary of Project -

The objective of the project is to conduct studies of advanced waste treatment processes and to demonstrate that the reclaimed secondary effluent is suitable for re-use and injection into underground aquifers. The project will provide operating data on advanced waste-treatment processes and allow optimizing the economics of the process. It will also demonstrate the effectiveness and reliability of advanced waste treatment as a method of providing water for re-use from secondary treatment plant effluent.

C-4

Treatment needed by sewage before injection - well recharge

Performing Organization

State Department of Health
84 Holland Avenue
Albany, New York 12208

Supporting Agency

Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/70 to 6/71	N/A	N/A

Summary of Project -

A study to investigate the mechanism of clogging and its reduction to increase the recharge capacity of the injection well. Various methods of tertiary treatment were used (rapid sand filtration, diatomite filtration, carbon filtration), including degasification, chlorination and the application of bivalent ions, to produce an optimal effluent for injection.

The distance that various constituents of sewage travel through saturated soil was also investigated by continual observations of the water quality in the observation wells. The project began in 1964 and was completed in mid-1969. The final project report has been received by the New York State Department of Health.

C-5

Treatment and disposal of complex chemical wastes

Performing Organization

State Geological Survey
P.O. Drawer O
University, Alabama 35486

Supporting Agency

Environmental Protection Agency
Office of Water Programs

Period	Man Hours	Funds
7/70 to 6/71	N/A	N/A

Summary of Project -

The proposed research will provide a means of treatment and disposal of complex chemical wastes consisting of five major efforts: (1) Phase I - Drilling and testing of a deep well, (2) Phase II - Completion of deep well for waste injection, (3) Phase III - Surface installation for deep well system, (4) Phase IV - Installation of surface plant for total treatment, and (5) Phase V - Operation, maintenance and monitoring of total system.

All phases will be involved in standard procedures and concurrent research development of methodologies and/or techniques that will permit projections of the fate of the chemical wastes and assimilative capacity of underground formations for the waste to be studied. The deep well phase will be carried to a point of decision and if the deep well does not prove feasible an alternative method of waste treatment and disposal will be initiated.

The work will be performed on the Reichhold Chemical property in Tuscaloosa.

C-6

Treatment and disposal of complex chemical wastes

Performing Organization

State Geological Survey
P.O. Drawer O
University, Alabama

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	$939,525

Summary of Project -

This study is to develop and evaluate a surface or subsurface method for control of pollution from a complex chemical waste from a petrochemical complex, manufacturing alkyl resin and phenols. Also to develop methodology and/or testing techniques to permit projections of: (1) the fate of waste components, and (2) the waste assimulative capacity, of deep geological formations.

C-7

Treatment needed by sewage before injection well-recharge

Performing Organization

State Department of Health
84 Holland Avenue
Albany, New York 12208

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	$72,450

Summary of Project -

The study is to define the treatment needed by trickling filter effluent before injection-well recharge.

Project Objectives: To determine the treatment required by trickling filter effluent for injection into ground water formation. Project Period: 1/1/65 - 3/31/69. Product Director: Dr. Leo J. Hetlin, Director, Research Unit Environmental Health Services, New York State Department of Health, 84 Holland Avenue, Albany, New York 12208. Financial Officer to Receive Funds: Marion L. Henry, Treasurer, New York State Department of Health, Health Research, Inc., 8 Holland Avenue, Albany, New York 12208.

C-8

Consolidation of available subsurface saline water analyses

Performing Organization

U. S. Department of the Interior
Bureau of Mines
Washington, D.C. 20240

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs

Period	Man Hours	Funds
7/71 TO 6/72	N/A	$35,000

Summary of Project -

This research is to establish an automatic data processing reference system for subsurface saline waters in the Storet format, which can be utilized in establishing the sources of ground water and surface water pollution resulting from oil production, deep well disposal, inadequately plugged oil wells, etc. For example, information concerning subsurface saline waters from any area in the U.S. would be obtained rapidly with the system for use in comparison with a polluted water. The computer system could be used to plot water analysis diagrams for use in saline water intrusion studies, and predictions of possible pollution areas can be made for use in pollution prevention.

C-9

North Fork alluvial decontamination project

Performing Organization

West Central Texas Municipal Water District
Abilene, Texas 79604

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	$264,023

Summary of Project -

This project is to demonstrate the abatement of surface water pollution caused by oil production which brings seepage from shallow ground water aquifers using deep well disposal techniques.

C-10

Compatibility of subsurface reservoirs with injected liquid wastes

Performing Organization

University of Alabama
Natural Resources Center
University, Alabama 35486

Supporting Agency

U. S. Department of the Interior
Office of Saline Resources

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

The proposed research plan involved laboratory determination of the long-term effects (compatibility) upon the physical parameters of subsurface rock formations resulting from the disposal of liquid wastes in deep-well injection practices. Purpose is to determine the extent of change in volumetrics and permeability of disposal reservoirs which may limit the economic practicability of this disposal method.

Laboratory methods employed: 1. Chemical analysis of reservoir fluids, rock matrix, and cementing materials of selected subsurface reservoir rock samples. 2. Determination of potential receptive horizons. 3. Injection of typical industrial liquid wastes into core samples under both surface conditions and elevated conditions of temperature and pressure over nominal to long periods of time to simulate actual reservoir conditions. 4. Re-examination of injected samples to determine changes in physical properties subsequent to long-term injection. 5. Chemical analysis of interstitial precipitates formed.

Data analyses were directed toward prediction of effects of waste types on physical properties critical to receptivity and volumetrics of identified geologic horizons. Compatibility and criteria will be formulated as a guide to the nature and volume of specific waste types which may be disposed of under limitations of local geologic conditions.

C-11

Computer modeling of rock-water interactions

Performing Organization

U. S. Department of the Interior
Geological Survey
18th & F. Streets N.W.
Washington, D. C.

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

This project is to develop a computer model which accurately predicts the chemical effect on the subsurface environment when waste fluids, such as the effluent of typical industrial processes, are injected into an aquifer. The desired output of the model is (1) a detailed prediction of the chemical interaction between the injected fluid, the aquifer brine and the rocks; (2) the identity and amounts of products formed by reaction; (3) the amount and composition of material absorbed onto mineral surfaces; (4) the thermodynamics of the processes in terms of pressure, temperature and volume changes; and (5) their distribution in space and time. These in turn predict changes in porosity, permeability and other factors important to the hydrologic regime. Essential input into the model includes not only the geological and chemical parameters describing the particular situation to be modeled, but also the thermochemical parameters characterizing the mineral and solution phases.

C-12

Advanced waste treatment for water reclamation and re-use by injection

Performing Organization

Nassau County Department of Public Works
Mineola, New York 11501

Supporting Agency

U. S. Environmental Protection Agency
Office of Research & Development

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project

The objectives of this project are to conduct studies of advanced waste treatment processes and to demonstrate that the reclaimed secondary effluent is suitable for re-use and injection into underground aquifers. This project will provide operating data on advanced waste treatment processes and allow optimizing the economics of the process. It will also demonstrate the effectiveness and reliability of advanced waste treatment as a method of providing water for re-use from secondary treatment plant effluent.

C-13

Corrosion and water treatment

Performing Organization

Standard Oil Co. of Indiana
P.O. Box 591
Tulsa, Oklahoma 74102

Supporting Agency

Standard Oil Co. of Indiana

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

This includes research to combat corrosion by inhibitors, cathodic protection and coatings. Water treatment research is directed to water quality for injection in flooding projects and for disposal in wells or at the surface. Current emphasis is on inhibitor development for wells with high temperatures and corrosive conditions and on cathodic protection in hostile off-shore environments.

C-14

Acid emulsion breaking-activated sludge for bakery waste

Performing Organization

Ebinger Baking Company
Maxess Rd.
Huntington, New York 11746

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs

Period	Man Hours	Funds
7/72 to 6/73	N/A	$129,729

Summary of Project -

Development and demonstration of acid emulsion breaking pre-treatment, activated secondary treatment, and multimedia filtration effluent polishing suitable for subsurface injection disposal. Treatment of 80,000 gpd effluent from a sweet-goods bakery was to be demonstrated.

Develop, design, construct, operate, and evaluate waste treatment plant.

Make techical and operation data available for use by others in the industry.

C-15

Computer modeling of rock-water interactions

Performing Organization

U. S. Department of the Interior
Geologic Division
Washington, D.C. 20242

Supporting Agency

U. S. Department of the Interior
Office of Saline Water
(Multiple Support)

Period	Man Hours	Funds
7/73 to 6/74	N/A	$138,067

Summary of Project -

The objective is to adapt a computer model which predicts the interactions between rock and brines to problems related to geothermal brine disposal and reservoir recharge. the desired output is (1) a detailed prediction of the chemical interaction among the injected fluid, the aquifer brine, and the rock; (2) the identity and amounts of products formed by reaction; (3) the thermodynamics of the processes in terms of temperature, pressure, and volume changes; and (4) their distribution in space and time.

Basic thermochemical principles are used to describe the chemical processes occurring between brine and rock minerals. As a first approximation, the reaction between the brine and the rock is considered an irreversible process while possible products are assumed to form reversibly.

Every effort will be made to obtain the most accurate, internally consistent and thermodynamically correct set of data for use in the program. The critical evaluation of existing data and the use of calorimetry, solution chemistry, phase equilibria, and crystallography to redefine poor values in the existing data will be used.

C-16

The evaluation of aquifer systems as processing plants for the modification of the composition of injected water

Performing Organization

Louisiana State University
School of Geosciences
University Station
Baton Rouge, Louisiana

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Res.

Period	Man Hours	Funds
7/73 to 6/74	N/A	$13,000

Summary of Project -

The proposed research is intended to quantify the mechanisms which control water composition in selected Gulf Coast fresh and saline aquifer systems. If successful, the results will permit the geochemical evaluation of these aquifer systems for: 1) the storage of injected waters, and 2) for the controlled modification of the composition of injected water. Some fresh water aquifers could conceivably be used as water softening plants of large capacity. At depth, saline aquifers may serve for the permanent containment of dissolved metallic and radioactive wastes by exchange and fixation.

The study will combine the following methods: 1) the interpretation of existing water analyses to quantify changes in water composition which have accompanied a) progressive withdrawal of natural waters and b) mixing of diverse water types; 2) the experimental investigation, under controlled conditions, of reaction and exchange of material between aquifer sediment and waters of specific initial composition; and 3) the numerical modeling of processes of reaction and mass transport in 1) and 2) above.

C-17

Treatment processes - wastes pumped from septic tanks

Performing Organization

University of Connecticut
Graduate School
Storrs, Connecticut

Supporting Agency

U. S. Environmental Protection Agency
Office of Research & Development

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

A three-year study of the characteristics, volumes, appropriate treatment and handling methods of septic tank sludge was conducted. Public attitudes and policies toward septic tank sludge treatment and disposal were determined by interviews and questionnaires. Pilot studies of treatment and disposal by soil injection, aeration-anaerobic digestion-filtration system, and controlled addition to a small municipal sewage treatment plant were conducted.

C-18

Spatial distribution of chemical constituents in ground water

Performing Organization

U. S. Department of the Interior
Geological Survey
Arlington, Virginia 22209

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$50,500

Summary of Project -

There is a need to be able to predict the chemical and physical changes that occur within an aquifer owing to stresses imposed upon the hydrologic system. These stresses may be the result of natural or artificial recharge of good quality water from injection of waste water or from withdrawals of water supplies.

To understand the chemical reactions between water and earth materials; these reactions are the processes by which the water attains the observed chemical character.

To describe the field relationships between the chemistry of the water and the geologic and hydrologic environment, and to identify problems that are amenable to solution by application of chemical thermodynamics; to identify and measure the variables that control the environment; and to interpret the measurements within the theoretical framework provided by reversible and irreversible thermodynamics.

C-19

Chemical reactions at mineral surfaces

Performing Organization

U. S. Department of the Interior
Geological Survey
345 Middlefield Rd.
Menlo Park, California

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$13,300

Summary of Project -

When solutes are introduced into a ground water system, as in artificial recharge or waste injection, chemical reactions may occur between introduced and native materials. The reactions may precipitate solids that interfere with water movement, generate gases or bring about various physical and chemical changes in the system surrounding the injection site. These changes may influence water movement and/or composition. Mineral surfaces tend to catalyze some of the more important chemical reactions but the effect is poorly understood.

To study effects of specific mineral surfaces on rates of such chemical reactions as hydroxide or carbonate precipitation, relating rate to nature and area of surface exposed, and determining rate constants and related numbers that can be used for design or evaluation of actual field operations.

Experiments will be conducted in the laboratory using physical-chemical techniques to characterize surfaces and measure reaction rates at various temperatures.

Presence of fine-grained inert solid minerals has been found to accelerate strongly the polymerization of aluminum hydroxide in solutions to which aluminum has been added and pH is slightly below neutrality. The rate of polymerization is directly related to specific surface area of minerals present. Methods for measuring the surface areas have been compared and adapted for use with various mineral forms.

C-28

Denver water quality modeling

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

The accidental or planned injection of fluids into the ground-water storage system will cause a change in the water quality as well as the water quantity of that system. Prediction of this change is necessary to allow a decision making capability prior to injection as well as to provide remedial action in case of accidental contamination. Prediction of water quality is also necessary to solve "inverse problems", that is the determination of aquifer-parameters through various tracer tests.

To predict water quality changes during solute transport through the saturated ground-water systems and to analyze the effects of these changes on the ground-water environment.

Solve the mass transport equation through numerical means using finite difference and Galerkin methods and thus produce a water quality model that will predict the effects of various chemical disturbances on the ground-water system. Evaluate the effects of these disturbances on the aquifer. Involve a systems orientated approach concentrating on the use of field data rather than laboratory experiments to verify the model.

C-21

Gases and solute complexes in water

Performing Organization

U. S. Department of the Interior
Geological Survey
18th & F. Streets, N. W.
Washington, D. C.

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Progress in studies of the geochemistry of water depends in part on more detailed knowledge of water compositions. The extent of complex formation and the concentrations of dissolved gases are among the properties which must also be determined. Studies for which such additional information is necessary include the geochemistry of ground waters in carbonate and sulfide rocks, the reactions occurring at lake bottoms, and in flooded mines, and subsurface waste disposal studies.

The objectives of the project are to develop techniques for determining kinds and concentrations of dissolved gases and solute complexes in natural waters, and to apply the resulting methods to the solution of particular geochemical problems.

The analytical capability for the chromatographic analysis of dissolved gases will be refined and enlarged to include all of the naturally occurring gases. Improved gas sampling devices, capable of collecting water samples uncontaminated by the atmosphere, will be developed and tested. The solute complex phase of the project will be concerned with refining our estimates of complexing in real systems for which published stability constant data are inadequate to account for observed water compositions. Techniques to be used will include ultraviolet and visible spectrophotometry, potentiometric and specification electrode methods and eventually infrared spectrophotometry and other methods.

G-32

Significance of oil field brine in reservoir geochemistry

Performing Organization

U. S. Department of the Interior
Bureau of Mines
Bartlesville, Oklahoma

Supporting Agency

U. S. Department of the Interior
Bureau of Mines

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

Samples of petroleum and natural gas reservoir fluids and rocks are obtained from selected areas. The samples are analyzed and the resultant data together with related geological data are integrated and interpreted by using maps and computer correlation techniques. Significant results are published to aid federal and non-federal agencies in evaluating reservoirs, in improving exploration and production methods, in evaluating strata for use in waste disposal, and in evaluating the economics of recovering minerals from brines.

ENGINEERING (RESERVOIR AND GEOLOGIC) STUDIES

E-1

Statistical porous media hydrodynamics

Performing Organization

University of Illinois
Urbana, Illinois 61801

Supporting Agency

Office of Water Resources Research
Department of the Interior

Period	Man Hours	Funds
7/66 to 6/68	N/A	$21,140

Summary of Project -

A previously established analogy between energy-based statistical mechanics and mass dispersion in transport phenomena is extended to stationary and non-stationary dispersion in flow through porous media. A detailed analysis is made of the pertinent thermodynamic equations and their corollaries in mass-based statistical mechanics are to be established. The project has a direct bearing upon the theory of movement of pollutants in ground water.

E-2

Dispersion in flow through non-homogeneous porous media

Performing Organization

Department of Civil Engineering
University of Wisconsin
Madison, Wisconsin 53706

Supporting Agency

University of Wisconsin

Period	Man Hours	Funds
7/65 to /69	N/A	N/A

Summary of Project -

In the study of dispersion in non-homogeneous porous media, a general solution for the distribution of a contaminant in flow through a layered or continuously graded porous media has been obtained. The resulting expression is simple and easily adapted to any arbitrary non-homogeneity. The basic feature of the analysis is that it treats the media as a continuum with a spatially varying dispersion coefficient. In this way the boundary conditions at the interface between successive layers are automatically satisfied.

For two and three layer systems, the solution has compared very well with experimental data. Though this work has been directed at one-dimensional, uniform flow, these results can be easily adapted to non-uniform flows (such as well pumping and recharge systems) in cases where longitudinal dispersion dominates the pollutant distribution.

For flow through non-homogeneous media in which lateral dispersion is important (i.e., flow parallel to the layers), a solution using the results obtained above, is being attempted. For a two-layered system, a solution has been obtained. An attempt will be made to extend this to a more general layered system.

E-3

Injection of chemicals into underground

Performing Organization

Ministry of Transport
Road Research Laboratory
United Kingdom

Supporting Agency

Osaka City University
Japan

Period	Man Hours	Funds
7/71 to 12/72	N/A	N/A

Summary of Project -

Many sorts of chemicals were injected into the ground. There is only one method of injection and the effects are compared with each chemical used in the process. Uniaxial compression test, triaxial compression test, dry pit values, elastic wave method, chemical analysis and other tests are employed to evaluate resulting properties of treated soil.

E-4

Movement and mixing of water injected into aquifers

Performing Organization

Massachusetts Institute of Technology
School of Engineering
Cambridge, Massachusetts 02139

Supporting Agency

Department of the Interior
Federal Water Quality Administration

Period	Man Hours	Funds
9/70 to 8/71	N/A	N/A

Summary of Project -

The research program is concerned with the replenishment of ground water aquifers by injection of water through recharge wells. The injected water may be a treated waste effluent or it may have other water quality characteristics, such as salinity, which differ from the native ground water. The primary objectives are to determine the quality of water pumped from the aquifer after mixing the dilution due to the recharge.

The movement and mixing of the injected water is effected by the natural flow existing in the aquifer and by the flow pattern induced by the injection and pumping wells. A single well may be used both for injection and pumping on an alternating basis. It is desired to develop analytical methods for the prediction of mixing and dilution for various boundary conditions and for both steady and unsteady flow fields. The distribution of concentration of any material introduced into the aquifer by means of the injection well is to be determined by numerical solution of the convective-dispersion equation. Longitudinal and lateral dispersion is considered in addition to the mass transport by the convective action.

The influence of density variations due to dissolved salts on the mixing of injected water were studied in the final stage of the research programs.

E-5

Dispersion of contaminants in jointed rock

Performing Organization

Northwestern University
Evanston, Illinois 60201

Supporting Agency

University of Illinois

Period	Man Hours	Funds
7/70 to 6/71	N/A	N/A

Summary of Project -

Deep injection wells into jointed rock strata provide one of the promising methods for the disposal of certain liquid wastes. However, relatively little is known about the characteristics of flow behavior in jointed rock. From a water resources point of view, such knowledge is very valuable when appraising the long-term quality of water from a jointed rock aquifer. Accordingly, the objectives of this research are (1) to formulate a basic seepage law for the flow of homogeneous fluid through jointed rock, and (2) to develop a theoretical model for the dispersion of a miscible contaminant into a homogeneous parent fluid which saturates a jointed rock stratum.

The investigation will be both theoretical and experimental in nature, and emphasis will be placed on plane and axisymmetric artesian flow under steady conditions. The entire practical range of Reynolds numbers will be investigated both for uniform seepage flow and for dispersion. The experimental model will consist of an orderly array of impermeable prismatic blocks separated by relatively narrow flow channels which will intersect at various angles. Concurrent with the development of an experimental flow law for this system, a theoretical analysis, based on a finite difference solution of the Navier-Stokes equations, will be performed. Hopefully, the synthesis of the experimental and theoretical results will lead to the development of a model which will have broader application to more complex systems.

E-6

Demonstration project for temporary detention of storm and combined sewage in the natural underground formations

Performing Organization

South St. Paul City Government
South Saint Paul, Minnesota 55075

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	$380,000

Summary of Project -

The objective of the project is to demonstrate the feasibility of using natural permeable underground strata in the South St. Paul, Minnesota, area for temporary storage of both storm water and combined sewage during periods of storm runoff. Prior to introduction of waste waters into the ground, they will be treated by removal of suspended solids, and will be chlorinated, if necessary, to eliminate danger of contaminating adjacent sources of water supply. Waste water entering the ground during storms will be pumped out over a period of several months. If the quality of water meets the required standards, it will be returned directly to surface streams. Otherwise, it will be transported to the sewage treatment plant.

The project will be conducted in three phases of six months each to consist of: Phase I, location of suitable underground strata and study of methods of solids removal; Phase II, tests using city water, construction of treatment facilities, and demonstration with storm water; and, Phase III, demonstration of the concept using combined sewage. Evaluation of each phase must demonstrate feasibility before the following is started.

H-7

Effects of density stratification on aquifer mixing

Performing Organization

Massachusetts Institute of Technology
School of Engineering
Cambridge, Massachusetts

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs
(Multiple Support)

Period	Man Hours	Funds
7/71 to 6/72	N/A	$28,086

Summary of Project -

The proposed research is concerned with the mixing of water injected into ground water aquifers through wells. The ultimate objective is to provide methods of predicting water quality when aquifers are used as storage areas for surface waters or disposal of wastes. The work has possible application in the area of thermal pollution in that ground water aquifers may serve as disposal areas for hot water.

The research will be primarily concerned with the role of density stratification on mixing in ground water aquifers. When the density of the injected water differs from that of the native water, a substantial increase in effective mixing would be expected. Actual application may involve storage of fresh water in aquifers containing brackish water or injection of hot water into a cool aquifer. The combined effects of dispersion and density differences will be studied analytically and experimentally.

E-8

The effect of pore fluid pressure on friction on fault and joint surfaces

Performing Organization

University of Texas
School of Engineering
200 W. 21st
Austin, Texas 78712

Supporting Agency

University of Texas

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

The mechanism of friction along weakness planes in the earth crust is thought to play an important role in earthquakes, slope stability and movements around water reservoirs and fluid injection wells. The objective of the investigation is to study the effect of pore fluid pressure on the friction characteristics of rock surfaces, particularly if through variation of the pore fluid pressure sliding can be induced under a given state of stress.

E-9

Mechanical and frictional behavior of rocks in fluid environment

Performing Organization

Martin Marietta Corporation
1450 S. Rolling Rd.
Baltimore, Maryland 21227

Supporting Agency

U. S. Department of Defense
Defense Advanced Research Project Agency

Period	Man Hours	Funds
7/73 to 6/74	N/A	$40,000

Summary of Project -

Investigate the control of faulting near waste injection wells by modification of rock surface hardness. This may be accomplished by pretreatment of waste fluids prior to injection so that frictional resistance of the faulted rock surface is increased.

The influence of various aqueous and non-aqueous surface-active environments on the near-surface flow and flow-dependent frictional behavior of several simple minerals will be investigated in the laboratory of RIAS with the idea of developing simple and economic procedures for treating fluid wastes prior to injection so that the possibility of triggering earthquakes is reduced.

E-10

Workshop in conjunction with engineering foundation conference - need for national policy for the use of underground space

Performing Organization

National Academy of Sciences
2101 Constitution Ave., N.W.
Washington, D.C. 20037

Supporting Agency

U. S. National Science Foundation
Division of Social Sys. & Human Resources

Period	Man Hours	Funds
8/73 to 4/74	N/A	$18,600

Summary of Project -

Generally, competing uses for underground space are increasing with improved subsurface excavation and drilling technology and with increased costs for use of surface space. There is an important need to understand how different claims on the underground space resource are made and how they compete with each other. This study will bring together engineering expertise and interest with that of economists and lawyers. The results will be definitive of how the market for underground space operates or fails to operate, and recommendations for planning goals consistent with equitable and efficient utilization of the resource.

Specifically, this effort will allow economists and lawyers to be brought to the Engineering Conference to discuss the legal regimes controlling mining, oil and gas drilling, water rights, tunneling, underground storage of waste or fuel, natural processes, and the geothermal resource. The perspective given will be both historical with regard to the development of existing laws and prospective with regard to how new laws might develop.

E-11

The storage of fresh water in saline aquifers - the effect of aquifer dip on the efficiency of a multi-well system

Performing Organization

Louisiana State University
School of Engineering
University Station
Baton Rouge, Louisiana

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research

Period	Man Hours	Funds
7/73 to 6/74	N/A	$20,000

Summary of Project -

Previous work has evaluated the fresh water recovery efficiency of a well field in a horizontal saline aquifer that was used for water storage purposes. Experimental observations on a small, artificial aquifer composed of epoxy-cemented, uniform blasting sand was used to verify and validate computational procedures. The work proposed here will consist of series of runs on the same mini-aquifer which will be tilted to predetermined dip angles and, simultaneously, the preparation of a computational program that can be used to compute the results to be expected at any dip angle, if the needed aquifer parameters are known. In view of the computational problems of recovery efficiency encountered when the factor of dip was lacking, a very complete set of experimental data will be obtained so that, if nothing else, empirical or semi-empirical correlations can be made. The results of the work will be usable, not only in the utilization of aquifers for the storage of fresh water, but in computing the movement of wastes, when a saline aquifer is used as the receiving volume of the management of wastes, subsurface.

E-12

A study of transient mass transport around waste injection wells in Illinois

Performing Organization

University of Illinois
State Geological Survey
Natural Resources Building
Urbana, Illinois

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research
(Multiple Support)

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

Hydrogeologic studies together with mathematical modeling are being used to investigate the fate of the liquid wastes injected into ground water reservoirs by deep injection wells in Illinois and the long range hydrodynamic effects of such injections on overlying aquifers. The work is being conducted according to the following procedure: A) the hydrogeologic investigations consists of collection and evaluation of hydrogeologic data on a local basis for a horizon currently under injection; B) the development of at least two mathematical models, to describe the transient state of pressure and contaminant concentration at any point in the injection horizon. These models must represent the spatial and time variations of the physical and chemical properties of the system as much as possible; C) the numerical solution of the models utilize the results of A and B and the numerical solution of the models obtained by finite element and Galerkin's methods; D) data from field observations will be collected to correlate the results of the solution with actual field data.

E-13

Study of mass transport around liquid waste injection wells in Illinois

Performing Organization

University of Illinois
School of Engineering
Urbana, Illinois 61801

Supporting Agency

University of Illinois

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

There are three activities in this study: (1) the derivation of mathematical models for mass transport phenomena in porous media; (2) the collection of geologic data; (3) the development of efficient techniques to solve the matrix-vector equation that results from applying the finite element method to the pressure equation. The techniques employ an adaptive-Chebyshev-factorization method to allow the use of up to 5,000 node points. Other methods are restricted to 1,000 node points.

E-14

Permeability restoration in underground disposal reservoirs

Performing Organization

University of Alabama
Natural Resources Center
University, Alabama 35486

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research
(Multiple Support)

Period	Man Hours	Funds
7/72 to 6/73	N/A	$8,841

Summary of Project -

The proposed research plan involves laboratory procedures seeking to develop technology for restoration of permeability and related physical narameters of underground liquid-waste disposal reservoirs wherein the injective capacity has been impaired by the physical and chemical interaction of injected liquid wastes and the rock matrix, native fluids, and other interstitial pore material.

Laboratory investigations will employ the following techniques: (1) determination of porosity and permeability of selected reservoir rocks; (2) injection of typical industrial liquid wastes under simulated reservoir conditions over nominal or long periods of time to determine the resulting permeability diminution; chemical analysis of fluids utilized; (3) employing mechanical and chemical methods of restoration of permeability and receptive capacity of the injected core samples; (4) comparing the effectiveness of various permeability restoration procedures by data analysis, wherein the permeability history is expressed mathematically. These relationships will be obtained by curve-fitting techniques and use of a digital computer.

Data analysis and reporting will be directed toward providing techniques for field application of methods of permeability restoration and rehabilitation of underground waste-disposal reservoirs where the injection capacity has been impaired as a result of the incompatibility of injected wastes and native pore materials.

E-15

Finite element modeling of anisotropic ground water movement with interfaces

Performing Organization

State University of New York
School of Engineering
Hayes Hall B, Rm. 1
Buffalo, New York

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research

Period	Man Hours	Funds
7/73 to 6/74	N/A	$33,444

Summary of Project -

It is proposed to investigate the ground water movements in isotropic and anisotropic porous medium. The only one continuum concept is adopted and a mathematical model is set up for a multi-liquid system which permits the inclusion of the heterogeneous physical parameters involved. The finite element method will be developed to obtain the numerical solutions of the following problem areas: 1. Transient (and steady state) solutions of isotropic porous medium flows including the movements (and equilibrium position) of the interfaces, drainage, deep-well disposal, withdrawal-recharging, up-coning, etc. 2. Sea water intrusion into confined aquifer. 3. Sea water intrusion including phreatic surface and interface. 4. Transient solution of sea water intrusion into anisotropic porous medium including the movements of the phreatic surface and interface.

Modeled problems will be set up so that the numerical solutions may be compared with known experimental data. Realistic physical parameters will be used whenever they are applicable.

E-16

Pressure-fracture gradient problems in deep well waste disposal

Performing Organization

University of Alabama
School of Engineering
University, Alabama

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research
(Multiple Support)

Period	Man Hours	Funds
7/73 to 9/74	N/A	$9,329

Summary of Project -

The proposed research is directed toward an evaluation of the relationship between pressure buildup in deep well waste disposal reservoirs and the fracture resistance of confining strata or aquicludes.

The investigation will consist of the following procedures: 1. Pressure buildup in disposal reservoirs in response to long-term injection of given volumes of waste will be determined, assuming that permeability of the reservoirs will diminish with time as a result of chemical reaction between the waste and native pore material. 2. The state of stress of reservoirs at various depths within the earth, the resulting fracture gradients, and the resistance to vertical fracturing of confining strata will be determined. 3. Maximum permissible pressure of volume of injected waste over the projected life of a disposal system that will insure the confining strata will not be subjected to fracturing stresses. 4. A computer program will be developed that will correlate pressure buildup with fracture resistance of confining strata, determine the elapsed time when injection must cease, and calculate capital investment and operating costs of disposal of given volumes of waste.

E-17

The finite element method in fluid mechanics

Performing Organization

Georgia Institute of Technology
School of Civil Engineering
225 N. Avenue, N.W.
Atlanta, Georgia

Supporting Agency

Georgia Institute of Technology

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

The finite element method is a powerful analytical tool in solving engineering problems. The present study is undertaken to explore the applicability of this method to hydraulic engineering.

Successful solutions have to be found in steady saturated subsurface flows. The application is to be extended to time-dependent problems. Its immediate usefulness may be in problems involving heat dissipation and the disposal of biologically or chemically degradable, or radioactive liquid wastes.

E-18

Transport properties of natural clays

Performing Organization

U. S. Department of the Interior
Geological Survey
Arlington, Virginia 22209

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$45,400

Summary of Project

Hydrologic studies concerned with the following problems: water supply, underground waste disposal, recharge, movement of contaminants, gas storage, and subsidence, are often hampered by the dearth of reliable information regarding the effect of fine-grained layers. The properties of interest regarding these layers are: hydraulic conductivity, storage coefficient, exchange capacity and osmotic efficiency. Clay minerals control these properties. At present these properties are difficult to predict and/or measure in the field or on undisturbed samples in the laboratory.

The objectives of this project are to continue development of meaningful measurement techniques for use in the field and laboratory determination of the properties of interest in fine-grained materials, and concurrently to increase the laboratory emphasis on delineating the factors which affect or control these properties with the goal of improving predictive ability based on relatively easily acquired data.

Complete a thorough evaluation of two completed field and laboratory studies resulting from this project in conjunction with the results of an additional similar study, to be published soon, and other data and results from related studies to determine the logical sequence of emphasis to achieve the objectives cited.

Analysis of a field and laboratory study regarding hydraulic properties of a confining bed deposited in an alluvial environment was completed. The lab and field results did not agree. Indications are that an apparent complex geological geometry was not adequately represented in the lab samples. Summarizing, studies to date have shown that representative samples analyzed properly in the lab provide meaningful data; however, the representatives of the samples is most important and often difficult to evaluate.

Initiate active laboratory investigations regarding the mechanisms affecting the behavior of fine-grained materials, primarily clay minerals, with respect to their transport properties as outlined in B1810. Initial efforts will concentrate on osmotic conductivity. Field work will also be conducted applying previously developed techniques for evaluating in situ properties of confining beds to an existing field problem.

E-19

Denver Hydrologic Laboratory

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$115,000

Summary of Project -

The capacity of an aquifer system to store and transmit water and to accept liquid wastes is governed in part by a variety of hydraulic, mechanical, and geologic characteristics that may or, in some cases, must be determined by laboratory testing. The usefulness of laboratory data may, however, be limited by the degree to which the measurements reflect the undisturbed in situ properties of the samples, and by the extent to which the samples are representative of vastly larger volumes of earth material.

The hydrologic laboratory provides a central facility to which geological survey projects throughout the United States may submit samples for testing of hydrogeologic properties. The continuing role of the laboratory is to provide reliable and meaningful data to such projects and, largely within the framework of current project needs, to develop improved and diversified methods of testing that will enhance the usefulness of laboratory data and contribute to the understanding of basic hydrologic principles.

Using samples submitted by field projects, the laboratory will continue research and development directed toward improving the reliability and reducing the costs of laboratory determinations. Particular emphasis is being placed on close laboratory simulation of the physical and chemical conditions existing in the field. Facilities for investigating the effects of proposed artificial recharge and waste disposal are being developed. Increased interaction with field projects during their planning stages has been developed, and whenever possible laboratory data are being correlated with the results of field tests and simulation modeling.

A constant-flow permeameter employing a precision infusion pump and sensitive pressure transducers was developed and put into routine operation. The test chamber is a low-pressure triaxial cell that permits moderate loading of the sample and eliminates bypassing. A high-pressure triaxial chamber was modified to permit testing the hydraulic conductivity and specific storage of samples at effective stresses up to 4,000 psi and pore pressures to 1,500 psi. Excellent data on the change of hydraulic conductivity with effective stress has been obtained.

E-20

Brine injection operation and management study

Performing Organization

U. S. Department of the Interior
Geological Survey
Charleston, West Virginia

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Oil and gas wells have been drilled in the Appalachian basin since the 1850's, and salt brine wells since the earliest 1800's. Current exploration and development of high water-to-oil ratio reservoirs in the basin has created a serious brine disposal problem. Most companies now inject brine into, just above, or just below the originating formation. Pollution of contiguous potable ground- and surface-water supplies has reportedly resulted from this practice in some places. This study will determine the feasibility of making a detailed study of the effects of brine injection at one site.

A favorable finding in this study will lead to the following project objectives: determine the practical limits of pressure and volume under which brine may be injected into fractured and possibly faulted oil reservoirs without harm to potable ground and surface-water supplies. Evaluate the effects of various injection rates and pressures on the behavior of the rock skeleton and native rock fluid, the growth of the pressure mound, and the production of seismic events of a typical Appalachian sandstone reservoir of Mississippian age.

Before a project proposal can be made, the following are necessary: (1) search the literature for previous studies of this problem; (2) incorporate the methods and techniques used in previous studies into a proposal for this study; (3) contact and confer with local officials to enlist their assistance in obtaining complete data at one oil field; (4) with local officials, obtain permission of oil company official to conduct the study in one limited oil field; (5) confer with survey analog model personnel concerning the construction and interpretation of models of the withdrawals and injections in the area.

E-21

Injection of produced water to prevent pollution and increase oil recovery - Wilmington Field, California

Performing Organization

U. S. Department of the Interior
Bureau of Mines
San Francisco, California

Supporting Agency

U. S. Department of the Interior
Bureau of Mines

Period	Man Hours	Funds
7/73 to 6/74	N/A	$[illegible]1,000

Summary of Project -

To determine how water produced crude oil in the Wilmington Field, California, may be economically treated and injected into the reservoir. Particular attention will be paid to the sources of all particulate matter that may prevent continued injection. The effects of other waters added to the water injection system will be studied for chemical and bacteriological stability. The size and quantity of solids in the injected waters will be correlated with the observed injectivity in the injection wells.

E-22

Underground injection, monitoring, storage, and disposal of industrial wastes

Performing Organization

U. S. Department of the Interior
Bureau of Mines
Bartlesville, Oklahoma

Supporting Agency

U. S. Department of the Interior
Bureau of Mines

Period	Man Hours	Funds
7/73 to 6/74	N/A	$200,000

Summary of Project -

The purpose of this project is to determine the parameters controlling the migration of industrial waste fluids injected into deep geologic formations. The objectives are to determine: (1) the maximum particle size of waste constituents that can be continuously injected into porous media having specific pore size distributions, (2) the ion exchange properties of various types of geologic formations, including four formations that are currently being used for waste injection, (3) the adsorption properties (rates and equilibria) of organic waste constituents in sandstone and carbonate formations under simulated subsurface conditions of temperature and pressure, (4) the rates and products of decomposition of organic waste constitutents in a subsurface environment, (5) to develop technology and procedures for evaluation of underground formations for injection of wastes and for monitoring procedures of injection systems.

Present research is concentrated on pore size distributions of porous media, the ion exchange and neutralization capacities of formations, and the adsorption and decomposition properties of organic waste constituents.

GEOLOGIC-HYDROGEOLOGIC STUDIES

GH-1

Investigations on the subsurface disposal of waste effluents at inland sites

Performing Organization

University of Arizona
Water Resources Research Center
Tucson, Arizona

Supporting Agency

Interior Department
Office of Saline Water

Period	Man Hours	Funds
7/68 to 6/70	N/A	N/A

Summary of Project -

Artificial ground water recharge investigations will be conducted to evaluate the applicability of recent theoretical, laboratory and field studies on mixing during miscible displacement, to waste disposal operations in inland alluvial sediments. The results will facilitate the establishment of rational guidelines for the selection and operation of artificial recharge facilities to preclude the impairment of native ground water supplies during subsurface disposal of waste effluent in inland areas with physical controls similar to those at the experimental site.

Recharge studies will be initiated at The Water Resources Research Center Field Laboratory, The University of Arizona, Tucson, using a blended, cooling-tower blowdown effluent. A series of "single-well" recharge-pumping trials will be conducted on a 150 ft. deep, 20 inch diameter recharge well. "Two-well" tests will consist of injecting effluent into the recharge well and, simultaneously, pumping from a downstream observation well. Recharge water will be tagged with fluorescent dye to facilitate preparation of breakthrough curves, using a recording fluorometer, during pumping. Tracer studies will also be conducted during recharge in a pit (100 ft. x 50 ft. x 10 ft., 3-1/2:1 side slopes). Water samples will be obtained from wells in the vadose and phreatic zones for preparation of breakthrough curves.

GH-2

The carbonate hydrogeologic environment, its relationship to land use, water resources development and management

Performing Organization

Pennsylvania State University
Inst. Res. Land & Water Resources
Land & Water Res. Building
University Park, Pennsylvania

Supporting Agency

U. S. Department of the Interior
Office of Water Resources Research

Period	Man Hours	Funds
7/71 to 6/72	N/A	$12,470

Summary of Project -

The geologic, topographic and land use factors that govern the occurrence, movement and recharge of ground water, the interrelationship among surface and ground waters, and the chemical quality of ground water related to the above is being studied for a terrain underlain by nearly 10,000 feet of folded and faulted carbonate rocks in central Pennsylvania.

Geologic and hydrologic factors pertinent to land use planning, and comprehensive water resources development and management will be investigated in this hydrogeologic environment. To accomplish this aim, stresses acting on the physical environment brought about by drought, urbanization, industrialization, recreation, etc., will be investigated and related to the physical environment response. Methodology of obtaining and evaluating relevant data will be improved upon to accomplish these objectives. Specifically, the importance of rock type, faults, folds, fracture traces and topography will be related to the permeability and storage characteristics of rocks, their relationship to recharge, stream flow and water quality. Geohydrologic factors relating site selection of sanitary landfills, storm water discharge, sewage effluent and industrial waste disposal will be investigated.

The overall hydrologic response of this complex aquifer and surface water system will be analysed using electrical analog techniques.

GH-3

Immobilizing wastes in impermeable rocks

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado 80225

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

Waste materials generated by DOD agencies and their contractors are considered an economic and social liability on the land surface. One of the most promising subsurface environments for emplacement of these wastes is that offered by salt deposits. Therefore, the objective of this project is to evaluate potential subsurface sites in impermeable rocks, particularly salt deposits, in terms of their geologic and hydrologic suitability for emplacement of wastes generated by activities of the Department of Defense.

GH-4

Waste emplacement, preliminary overview

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/73 to 6/74	N/A	N/A

Summary of Project -

A program to provide a summary of available geologic and hydrologic knowledge of selected areas and rock types, particularly salt, to aid the U. S. Atomic Energy Commission in its search for the best location for a pilot plant repository for underground emplacement of solid high-level radioactive waste. The project includes six report topics: 1) stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas, and New Mexico; 2) geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico; 3) halite occurrences in Arizona; 4) geologic and hydrologic summary of salt domes in Gulf Coast region of

Texas, Louisiana, Mississippi and Alabama; 5) potential waste disposal sites in Paradox and Eagle Basins, Utah and Colorado; 6) shale, mudstone and claystone as potential host rocks for underground emplacement of radioactive waste.

GH-5

Subsurface management of waste liquids

Performing Organization

U. S. Department of the Interior
Bureau of Mines
Morgantown, West Virginia

Supporting Agency

U. S. Department of the Interior
Bureau of Mines

Period	Man Hours	Funds
7/73 to 6/74	N/A	$100,000

Summary of Project -

The objective is to determine subsurface formations in West Virginia that are best suited for injection and storage of various waste liquids.

The underground storage of waste liquids is often desirable and necessary in preventing surface and subsurface fresh water pollution. The Kanawha River Valley, Charleston, West Virginia, has been selected for the initial study. This study is a cooperative effort with the West Virginia Geological and Economic Survey.

The Geological Survey will prepare location maps of all oil and gas wells in the area and also make structure, isopach, porosity, connate water saturation, reservoir pressure and fracture gradient maps of reservoirs in the area.

The Morgantown Energy Research Center will prepare maps of surface fracture traces and lineaments using the airborne remote sensors, side looking radar, and thermal infrared photography. Surface joint measurements, rock stress measurements and induced hydraulic fracture orientation field studies will be made to determine where possible vertical migration of injected waste liquids may occur or intersect abandoned or active oil or gas wells. Laboratory studies will be made of core material to evaluate the physical and chemical properties of the formations and their reaction to waste liquids and injection pressures. Engineering studies will be made of injection pressures and equipment, volumes and rates of injection of liquid waste. From these studies, locations for waste liquid disposal wells will be selected with the lowest probability of pollution to the environment.

GEOPHYSICAL STUDIES

GP-1

Seismicity and tectonic strainfields

Performing Organization

California Institute of Technology
Graduate School
1201 E. California Blvd.
Pasadena, California

Supporting Agency

U. S. Department of Defense
Air Force

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

Relation to DOD function and mission - This work supports research in the large shot seismicity phase of Arpa's military geophysics program. This is part of a coordinated DOD/AEC program to determine whether underground explosions are capable of triggering damaging earthquakes. The nature, and possible continuation, of the high-yield nuclear test program will, in part, depend upon the results of these measurements. In the last several years it has become increasingly clear that man's activities are able to interact with the tectonic strain field of the earth. Examples of such activities are reservoir loading, deep fluid injection, and underground testing of nuclear devices. It is also clear that natural earthquakes cause a change in the physical environment leading to stress release and aftershock, foreshock, and swarm sequences, or to periods of accelerated creep. A detailed study of the triggering problem of certain aspects of the regional seismicity problem will be investigated to determine source mechanisms, seismic energy propagation, strain accumulation and release. This research will provide the USAF with data to improve the identification of underground nuclear explosions and the understanding of stress and strain relationship for site selection.

GP-2

Laboratory investigation of earthquake generation by fluid injection

Performing Organization

U. S. Department of the Interior
Geological Survey
345 Middlefield Rd.
Menlo Park, California

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

Try to find out if it is possible to limit the size of elastic shocks during fluid injection into rocks subjected to a differential stress and high confining pressure.

GP-3

Childress M/Eq. Studies

Performing Organization

U. S. Department of the Interior
Geological Survey
345 Middlefield Rd.
Menlo Park, California

Supporting Agency

U. S. Department of the Interior
Geological Survey
Geologic Division

Period	Man Hours	Funds
7/71 to 6/72	N/A	N/A

Summary of Project -

This project is part of a larger program to study the relationship between earthquakes and fluid injection in wells. The current phase of the project is to gather data on the natural seismicity of the area prior to fluid injection. Future work will investigate the seismicity of the area after fluid injection begins to determine the relationship between earthquakes and fluid pressure.

GP-4

Tiltmeter instrumentation for deep borehole operation

Performing Organization

Arthur D. Little, Inc.
15 Acorn Park
Cambridge, Massachusetts

Supporting Agency

U. S. Department of Defense
Air Force

Period	Man Hours	Funds
7/72 to 6/73	N/A	$75,824

Summary of Project -

This effort is a part of the instrument development phase of Arpa's military geophysics program. Its purpose is to develop and test a new type of deep hole instrumentation to measure and continually record two components of tilt resulting from changes in the earth's strain field. These deep borehole tiltmeters are intended to be used in studies of the spatial and temporal distribution of earth strain caused by stress sources of natural (tectonic) origin or artificial processes, such as deep well fluid injection waste disposal, hard rock excavation, and underground nuclear explosions. Results of this work will contribute to the technical solution of DOD related problems associated with inadvertent generation of seismic activity by fluid injection in deep holes for waste disposal and by nuclear weapons testing, and with prediction of cavity behavior during the excavation of extensive underground openings in hard rock. Design of the instrument sensor is based on a diamagnetic suspension principle. Three instrument packages will be assembled and each will be subjected to operational and stability tests in shallow (approximately 100 feet deep) boreholes in an area where the earth tides can be deployed in deep (several thousands of feet) boreholes in a suitably spaced array to continuously record two components of tilt for interpretation of the changes in the regional strain field of the earth in the test location.

GP-5

Deep borehole stress measurement technique

Performing Organization

South Dakota School of Mines
School of Engineering
Rapid City, South Dakota

Supporting Agency

U. S. Department of Defense
Air Force

Period	Man Hours	Funds
7/73 to 6/74	N/A	$80,674

Summary of Project -

In situ measurements of the initial state of stress of rock masses provide one of the most important parameters for accomplishing the objectives of two phases of the DOD military geophysics program of Arpa -- fluid injection and waste disposal research for determining the susceptibility of rocks to fail during fluid injection into deep wells or filling of reservoirs resulting in the inadvertent triggering of hazardous earthquakes, and rapid excavation rock mechanics research for the design of both surface and underground openings in rock. A deep borehole instrument capable of making stress measurements in the side walls of uncased boreholes has been developed and lab tested and stress concentration factors unique to the geometry of the measurements have been developed under a previous contract. Combining the stress measurements and the concentration factors in calculations completely defines the state of stress at various depths in the ground. The deep borehole stressmeter will be tested in a shallow hole, modified if necessary, and then utilized at various depths in several deep boreholes in producing oil fields, seismically active areas, and reservoir sites to determine underground stress fields and their changes resulting from natural tectonic and man-made seismic activity.

GP-6

Triggering of earthquakes in Mississippi Valley seismic zone

Performing Organization

St. Louis University
School of Arts
221 N. Grand Boulevard
St. Louis, Missouri 63103

Supporting Agency

U. S. Department of Defense
Defense Adv. Res. Project Agency

Period	Man Hours	Funds
7/73 - 6/74	N/A	$40,456

Summary of Project -

To determine seismicity in the vicinity of a deep injection well at New Johnsonville, Tennessee.

Seismicity is to be monitored by a radio telemetered seismic array newly developed under fluid injection/waste disposal research program. Analysis and interpretation of data will be conducted and earthquake activity, if any, correlated with injection pressures and other data from the waste disposal well.

GP-7

Borehole geophysics as applied to geohydrology

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$89,000

Summary of Project -

Borehole geophysics is essential for a full understanding of the geologic framework within which water moves and provides a means for the extrapolation of hydrologic data to other areas. The techniques and degree of application of borehole geophysics to ground water hydrology are many years behind the petroleum industry. The maximum use of borehole geophysics will provide a greater data return for money invested in test holes and wells, sampling and sample analyses, and hydraulic tests.

The objectives of this research project are: to investigate, appraise, and report on the current and potential applications of borehole geophysics in ground water hydrology, to demonstrate the value of these techniques in various ground water environments, to adapt existing equipment for hydrologic purposes and to improve methods of quantitative log interpretation.

Many of the interpretive techniques and much of the logging equipment developed in the petroleum industry can be adapted to hydrologic investigations with a considerable savings in time and money. New equipment and techniques that are not available elsewhere are developed by project personnel for specific ground water applications such as artificial recharge and subsurface waste disposal. Close liaison with the equipment services unit results in a better understanding of field problems and a more rapid application of new developments to the field. All final testing is done in the field and relies heavily on the availability of other data on the wells logged.

Research was carried out on improving borehole flow meters. Thermal, strain-gauge, impeller and tracer probes were designed and tested. Geophysical logging as applied to artificial recharge to identify plugging of the aquifer and to measure water movement. Periodic temperature logs were used to determine the relative permeability and changes with time. A project on the application of geophysics to Karst hydrology was started in Yugoslavia. Specifications were prepared for the first regional logger and it was tested and accepted.

Testing and modification of borehole flow meters will continue with an evaluation report planned for later in the year. When flow meter research is finished work should start on a system for digitizing logs in the field. Field investigations will continue on artificial recharge and limestone hydrology near San Antonio, Texas, and Dubrovnik, Yugoslavia.

GP-8

Geophysical logging research as applied to subsurface waste storage

Performing Organization

U. S. Department of the Interior
Geological Survey
Denver, Colorado

Supporting Agency

U. S. Department of the Interior
Geological Survey
Water Resources Division

Period	Man Hours	Funds
7/72 to 6/73	N/A	$50,000

Summary of Project -

Investigations of subsurface waste storage rely on drilled holes for specific data on deep environments, but disposal into deep rocks imposes an economic limit on the number of test holes and monitor wells that can be drilled. Data on the capacity of the environment to accept and transmit certain fluids can be determined by coring and hydraulic tests using isolation packers. Geophysical logs can add three-dimensional information to core and test data, vertically in one well and laterally to other wells. Periodic logging also provides information on changes taking place in the well and rocks due to waste injection.

Adequate protective and developmental knowledge of deep waste storage basins in the United States will require an improved arsenal of borehole geophysical techniques. New and improved methodologies and equipment of the petroleum industry must be developed, modified, and tested for waste storage applications. Acoustic velocity and pulsed neutron logging capabilities will be added to the equipment already available in the Water Resource Division. The basic objective is to provide predictive information on the effect of injecting waste on the rock matrix and contained fluids.

The acoustic velocity and pulsed neutron logging equipment along with other logging techniques already available in the Water Resources Division will be applied to the study of proposed waste emplacement environments. Logs will be calibrated and collated with core and fluid analyses and the results of hydraulic tests using statistical and computer techniques. Because of the difficulty of building laboratory models to simulate in situ response of geophysical tools, the project will rely entirely on wells, analyses, and tests from other phases of the subsurface waste emplacement program.

In order to make room for additional logging equipment to be acquired for subsurface waste storage applications, the research logging van was moved to a larger truck and storage boxes and tubes were added. A 20 foot folding tower was designed and built on the truck so that acoustic velocity logs can be made in the absence of a drilling rig. The acoustic velocity system was tested and accepted. A comparison of velocities measured with this equipment and a Schlumberger borehole compensated system revealed discrepancies. Core samples from the hole have been selected for laboratory velocity and porosity analyses which will be used for log calibration.

MONITORING STUDIES

M-1

Application of remote sensing to hydrogeology

Performing Organization

University of Wisconsin
School of Natural Sciences
Madison, Wisconsin 53706

Supporting Agency

National Aeronautics and Space Administration
Organization & Management Office
University Affairs Office

Period	Man Hours	Funds
N/A	N/A	N/A

Summary of Project -

In continuation of our research on the application of remote sensing in the evaluation of shallow ground water flow systems, two landfill sites in the city of Madison, Wisconsin, were overflown with a Daedalus thermal scanner and PRT-5 (8-14 pr.) at altitudes between 1600-1800 feet. Simultaneously with the thermal flights, ground truth information was gathered and the data obtained are now being correlated with the imagery obtained by the thermal sensor. An analysis is being made of such masking effects as: vegetation and color of soils; depth to the water table; topography; diurnal soil temperature variations; heat conduction originated by the decomposition of the refuse.

Extensive ground water flow system evaluations, both physical and chemical, had already been accomplished at these two sites using conventional ground based techniques.

Hopefully, the results of these investigations will show some of the potentials and handicaps of remote sensed thermal imagery for local and basin-wide investigations of shallow ground water flow systems.

M-2

Use of precise ground water temperature measurement for detecting and tracking pollution spread in shallow basalt aquifer west of Melbourne

Performing Organization

Victoria Geological Survey
Melbourne, Victoria,
Australia

Supporting Agency

Victorian State Government

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

To provide a cheap and simple technique for monitoring movement of polluted ground water in the vicinity of effluent disposal bores.

Twelve observation bores were drilled at selected positions surrounding a bore used for underground disposal of industrial effluent. Disposal is into a basalt aquifer system which consists of an upper, unconfined and a lower, partly confined, aquifer. The aquifers show evidence of pollution and partial plugging.

To monitor water quality and movement, initial observations of the potentiometric surface and ground water quality were made by periodic water level observations, sampling and chemical analysis. This method proved both costly and time consuming. To overcome these problems, a method involving use of precise ground water temperature measurements in combination with continuous water level recording and regular determination of conductivity has been developed. An experiment is planned to begin immediately before the annual Xmas shut-down of the plant and will continue until after production resumes. As many boreholes as possible will be equipped with continuous water level recorders, and ground water conductivity will be recorded continuously from a single point in one borehole. All holes will be regularly logged for water temperature and conductivity at vertical intervals of five or ten feet using equipment accurate to 0.01 degrees C, especially developed for the purpose.

It is expected that the experiment will provide quantitative data on the rates of ground water movement and flow paths in three dimensions, and will also test the value of the method for similar investigations in other areas.

MISCELLANEOUS STUDIES

MI-1

Brine disposal treatment practices relating to the oil production industry

Performing Organization

University of Oklahoma
Research Institute
660 Parrington Oval, Room 101
Norman, Oklahoma

Supporting Agency

U. S. Environmental Protection Agency
Office of Water Programs

Period	Man Hours	Funds
7/72 to 6/73	N/A	N/A

Summary of Project -

Supply the oil field operator with sufficient information to implement the most satisfactory method of brine disposal while complying with state regulations.

A report will be prepared based on contacts with state agencies, oil companies, and salt water disposal companies. The text will include the principle and coordinating state agencies having regulatory responsibility for brine disposal; the date and title of the most current brine legislation; the disposal practices permitted and permit fees; and a mathematical model of disposal costs (capical and operating) as a function of disposal method, benefits of brine injection, size of the operation, and location.

SECTION XI

APPENDIX H

SUMMARY OF RESEARCH PROJECTS RELATED TO THE TREATMENT OF HAZARDOUS WASTES

Table 35 comprises this appendix. It lists the project and the performing and supporting agency. The period during which the project was undertaken is shown together with the manhours and funds incumbered when available. Data that were not available are indicated by N/A.

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SECTION XI

APPENDIX I

INVENTORY OF LEGISLATION, REGULATIONS, AND POLICY GOVERNING DEEP-WELL INJECTION

STATE

Alabama[1]

The Water Improvement Commission has jurisdiction over the disposal of industrial wastes. The Commission originally was established by Act No. 523, 1947 General Acts of Alabama, as amended. In 1965 the Commission was reorganized and its jurisdiction extended into areas of Water Pollution Control by Act. No. 574, 1965 General Acts of Alabama. There are no specific laws or regulations governing underground disposal.

A general summary of the information reviewed before approval of a deep-well system is as follows:

a. Volume of waste.

b. Physical and chemical properties of the waste.

c. Subsurface geologic investigations, study of well logs.

d. Depth and extent of usable ground waters and means of requiring their protection.

e. Depth and thickness, areal extent, and physical and chemical composition of formations designated as disposal reservoirs.

f. Hydrology of designated disposal formations and their expected performance over a period of years.

Alaska[1]

The Department of Health and Welfare is the state agency charged with the preservation of water quality standards. Title 46 of the Alaska Statutes describes their policy and functions. They would be the primary regulatory agency in the event subsurface disposal programs were adopted. In addition, the Department of Natural Resources, under Statutes 31, 05.030, also has authority to regulate the drilling, casing and plugging of wells to prevent pollution of fresh water. The regulations specifically apply to oil activities; however, the general wording indicates application to other subsurface programs. The State of Alaska Water Quality Standards and Implementation Plan has been submitted to the Secretary of Interior as part of the Federal Water Pollution Control Administration requirements and conditional approval has been given.

Arkansas[1,3]

The Pollution Commission was established under Act 472 of 1949 as amended by Act 183 of the 1965 Legislature (Section 82-1901, et seq., Arkansas Statutes) and are charged with regulation of any type of disposal system. Rule C-7 of the Oil and Gas Regulations specifies disposal of salt water or other water containing minerals. Permits would have to be obtained from both agencies. Applications for permits would need to comply with the existing C-7 regulations, as well as any regulations the Pollution Control Commission has.

Rule C-7 Disposal of Salt Water -

A. Application, Approval and Place of Disposal. Salt water or other water containing minerals in such amount as to be unfit for domestic, stock, irrigation, or other general uses, upon application to, and approval by the Commission may be disposed of by injection into the following formations:

   1. Non-producing zones of oil or gas-bearing formations that contain water mineralized by processes of nature to such a degree that the water is unfit for domestic, stock, irrigation, or other general uses.

   2. All non-producing formations, containing water mineralized by processes of nature to such a degree that water is unfit for domestic, stock, irrigation or other general uses; provided, that before such formations are approved for disposal use, it shall be ascertained that they are separated from fresh water

formations by impervious beds which will give adequate protection to such fresh water formations, and that fresh water supplies contained by the proposed disposal formation near its outcrop shall be at such a remote distance as not to be endangered by addition of mineralized water in the proposed disposal wells.

The Commission, in passing upon applications for the use of non-producing formations for disposal formations, will be advised by the technical recommendations of the State Geological Survey and the State Board of Health in determining whether such formations may be safely and legally used.

B. Casing and Cement. Disposal wells shall be cased and the casing cemented in such manner that damage will not be caused to oil, gas or fresh water resources.

Special requirements augmenting Section B --

"I. New Wells Drilled for Disposal:

A. On wells to be drilled to the Wilcox, operator may have the option of setting surface and cementing the long string a minimum of 250 feet above the top of the Wilcox, or not setting surface casing and circulating the cement to the surface on the long string.

B. On wells to be drilled below the Wilcox, operator shall be required to comply with the Minimum Surface Casing Requirements and cement the long string a minimum of 250 feet above any producing zone or above the zone to be injected into.

C. A cement bond log shall be required to be sure the cementing requirements are complied with.

D. An Induction log shall be required if there are no logs in the immediate vicinity of the proposed injection well to be used for correlation.

II. Old Wells Converted to Disposal Wells:

A. A cement bond log shall be required to be sure the cement behind the casing is a minimum of 250 feet above any producing zone or 250 feet above the zone to be injected into.

B. A Gamma Ray log shall be required if there are no logs in the immediate vicinity of the proposed injection well to be used for correlation.

III. Completion or Recompletion Reports shall be filed no later than 10 days after completion of the well."

C. Trial Test -- Application, Contents and Approval.

1. On application to and approval by the Commission trial tests may be made in the manner and for such duration as the conditions justify and the Commission may permit.

2. The application for a trial test shall be verified and filed with the Commission showing:

(a) the location of the disposal well

(b) location of wells and names of landowners and lessees within one-half mile of the disposal well

(c) description of formation and top and bottom depth where disposal water is to be injected

(d) elevation of the producing formations

(e) disposal well log and description of disposal well casing

(f) such other information as the Commission may require to ascertain whether the disposal may be safely and legally made

3. Approval for trial tests will be given by the Commission if after investigation it is found that the disposal may be safely made under the proposed plan.

4. Disposal water may not be injected into a disposal well for a longer period than a trial test without first complying with the requirements herein for permanent disposal.

D. Permanent Disposal -- Application, Contents, Notice, Objections, Hearing and Approval.

1. No disposal water shall be injected into a disposal well except for trial tests as provided in (C), until so ordered by the Commission pursuant to application and notice as herein required.

2. The application shall be verified and filed in triplicate with the Commission showing:

   (a) the location of the disposal well, abandoned and drilling wells and dry holes

   (b) the location of all oil and gas wells, including abandoned and drilling wells and dry holes, and the names of the landowners and lessees within one-half mile of the disposal well

   (c) the name, description and depth of the formation into which water is to be injected

   (d) elevations of the top of the producing formation in the disposal well and in all producing wells within one-half mile radius if the disposal water is to be injected into a lower horizon of an oil or gas-bearing formation

   (e) disposal well log

   (f) description of the disposal well casing

   (g) location of wells producing water to be injected into the disposal well

   (h) the estimated minimum and maximum amounts of water to be injected daily

(i) the name and address of operators notified of the application and the date that such notice was given

(j) such other information as the Commission may require to ascertain whether the disposal may be safely and legally made

3. Application may be made to include the use of more than one disposal well on the same lease or on more than one lease.

4. Applications shall be executed by all operators who are to participate in the proposed disposal plan.

5. Notice of the application shall be given by the applicant by mailing or delivering a copy of the application to each operator of producing and drilling wells within one-half mile radius of the proposed disposal well. Such notice shall be mailed to or delivered on or before the date the application is mailed to or filed with the Commission.

6. Objections or complaints, stating the reasons why the proposed plan as contained in the application may cause damage to oil, gas or fresh water resources, must be filed within ten days after the application is filed.

7. In the event any such objection or complaint is filed or the Commission on its own motion deems that there should be a hearing on the application, a hearing shall be had after reasonable notice of the time, place and subject matter of such hearing has been given to the parties in interest.

8. Orders approving the disposal plan will not be made within ten days of the filing of the application unless the written consent of all persons entitled to notice is filed with the Commission within such time.

E. Notice of Commencement and Discontinuance of Disposal Operations.

1. Immediately upon the commencement of disposal operations, the applicant shall notify the Commission of the same and the date of commencement.

2. The owner or operator of the disposal well shall keep an accurate record of the amount of water disposed of and such information shall be furnished the Commission monthly.

3. Within ten days after the discontinuance of disposal operations, the applicant or the one in charge thereof shall notify the Commission of the date of such discontinuance and the reasons therefore.

4. Before any disposal well shall be abandoned, notice shall be served on the Commission and the same procedure shall be followed in the plugging of such well as provided for the plugging of oil and gas wells.

California[19,22]

There is no specific legislation related to deep-well disposal of industrial waste in California. The Porter-Cologne Water Quality Control Act gives various state departments or agencies regulatory authority in Chapter 5.5 Section 13382 stating, "Waste discharge requirements shall be adopted to control pollutants into wells". The jurisdiction of regulation and enforcement probably will be with five agencies; the Water Resources Control Board, the Water Quality Control Board, the State Land Commission, the State Board of Health and the Division of Oil and Gas. The State Board of Health is specifically involved when septic tanks and sewage lagoons are involved and the Division of Oil and Gas, under the Public Resources Code, has control over all wells drilled or converted to waste water disposal from oil, gas or geothermal resources operations. The Division of Oil and Gas also acts as an advisor to other involved agencies and the Division's specific requirements for disposal wells as set forth in its Manual of Instructions (revised August 1973) apply to industrial deep-well systems; they state:

43. WATER DISPOSAL

A disposal well is any well used for the disposal of waste water from oil, gas or geothermal resources operations.

New wells may be drilled and old wells may be converted for water disposal service. Notices and bonds are required as for any other well.

Note: Water-injection wells will be classified by district offices as water flood (Sec. 42) or water disposal, according to primary purpose. Use best judgment in borderline cases.

Map symbols for water-disposal wells:

⌀ Water disposal
⌀ Oil well converted to water disposal
⌀ Dual producing and disposal well
⌀ Water disposal, Industrial
⌀ Gas well converted to water disposal
⌀ Abandoned gas well that had disposal

43.1 NEW PROJECTS

Data Required from Operator

In general, requirements are similar to those for production-stimulation wells (Sec. 42). However, data and exhibits need only extend or cover the disposal zone and shall consist of the following:

1. A cross section through the injection well, showing structural details and the following:
    a. Top, bottom, formation and age of injection zone.
    b. Base of any fresh-water strata, or a statement that none present.

2. A contour map on top of, or near the injection zone.

   Note: Items 1 and 2 above may be omitted if the Division has a recently published report and the operator states he accepts this interpretation of the geology, or if the well is so isolated as to preclude the filing of the information.

3. Source and analysis of the injection water and analysis of water in the injection zone.

4. Graphs of injection rate vs. pressure (to be submitted as soon as they are made).

5. Letter containing engineering details of the project, such as:

   a. Reservoir characteristics of injection zone, such as porosity, permeability, etc.

   b. Method of injection (casing, tubing, tubing with packer, between strings).

   c. Daily amount of water to be injected per well.

   d. Treatment of water to be injected.

   e. Maximum surface injection pressure anticipated.

   f. Condition of old, abandoned, idle wells in vicinity of injection well.

   g. Precautions taken, or to be taken, to ensure that injection fluid is confined to intended zone of injection.

6. Copies of letter of notification are sent to neighboring operators if deemed advisable by the deputy.

Approval of New Projects by Division

Projects may be approved by the district deputy without reference to the Supervisor. However, the deputy may refer to the Supervisor in advance if he has any questions or doubts.

In some instances, operators proposed to inject waste water into aquifers other than depleted oil reservoirs. Every effort should be made to confirm that all the injected water is confined to the intended zone of injection. Some aquifers are confined and if filled to capacity, there is the possible problem of the waste water migrating upward behind the casing of either the injection well or nearby producing wells. The condition of all wells within a half-mile radius should be such that all oil, gas and fresh water deposits are protected. A thorough knowledge of the stratigraphy and subsurface conditions is essential before permitting such disposal. Even so, these projects must be constantly and carefully scrutinized.

Upon receipt of data from operator in regard to a new project, Deputy replies by letter approving the project subject to our general requirements:

1. Form 105 or Form 107 shall be used whenever a new well is to be drilled for use as an injection well, or whenever an existing well is to be converted to an injection well, even if no work is required. (Specific requirements to be outlined in answer to the notice.)

2. A monthly report on Form 110-B shall be furnished this Division in duplicate, listing the amount of fluid injected and the surface pressure required for each injection well.

3. A chemical analysis of the fluid to be injected shall be made and filed with this Division prior to the start of injection, whenever the source of injection fluid is changed, or as requested.

4. A chemical analysis of the fluid in the injection zone shall be made and filed with this Division prior to the start of injection.

5. An accurate, operating pressure gauge or chart shall be maintained at the wellhead at all times.

6. Fluid injection profile surveys shall be required for all injection wells within one month after injection has commenced, at least once every year thereafter for all high-pressure or high-volume injection wells, after any significant anomalous rate or pressure change, or as requested by the Division, to confirm that the injection fluid is confined to the proper zone.

7. Sufficient data shall be maintained to show performance of the project and to establish that no damage is occurring due to excessive injection pressure. These data shall be available for periodic inspection by personnel from the Division.

8. Injection shall cease if any evidence of damage is observed or upon written notice from the Division.

It may be necessary to modify the above requirements or add other requirements to fit individual circumstances.

Do not send to headquarters duplicate copies of the material received from the operator. This material is to be sent to the State Record Center by the district office.

When reporting a chemical analysis of zone water or injection water, preferably use ppm as the unit. Reports of water analysis submitted by operators are generally given in parts per million or milligrams per liter.

Colorado[2,3]

Effective May 1, 1974, the Colorado Water Quality Control Commission has jurisdiction to regulate and control the subsurface disposal of industrial and domestic waste as contemplated by the Water Quality Control Act of 1973, (C.R.S. 66-28 as amended) and by C.R.S. (1963) 3-16-2 (6) as amended.

Rules for Subsurface Disposal Systems -

The Rules and Regulations for Subsurface Disposal Systems effective July 1, 1970, are repealed and repromulgated as follows:

Section 1 - DECLARATION OF POLICY. - These Rules provide the conditions for the location, construction and operation of subsurface disposal systems. After the effective date of the adoption of these Rules, no construction nor operation shall take place contrary to provisions of these Rules.

Section 2 - DEFINITIONS. - As used in these Rules:

(a) "Act" means the Colorado Water Quality Control Act of 1973, Chapter 66, Article 28, C.R.S. 1963 as amended.

(b) "Aquifer" means a permeable formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield quantities of ground water to wells or springs.

(c) "Coefficient of Storage" means the volume of water released from or taken into storage per unit surface area of the aquifer when the piezometric surface declines one (1) unit.

(d) "Commission" means the water quality control commission created by section 66-28-201.

(e) "Construction" when used with respect to a disposal system shall mean any initial creation of a new disposal system, any material modification or alteration of any existing disposal system, and the conversion of any condition or structure not previously used as a disposal system into such a system.

(f) "Disposal aquifer" is any aquifer into which wastes are intended to be disposed of by means of a disposal system.

(g) "Dispose" and "Disposal" mean the deposit, generation, creation, or discharge of any wastes at any level below the land surface.

(h) "Division" means the division of administration of the state health department.

(i) "Operate" when used with respect to a disposal system means the use or employment of that system to dispose of wastes below the surface of the land.

(j) "Person" means an individual, corporation, partnership, association, state, or political subdivision thereof, federal agency, state agency, municipality, commission, or interstate body.

(k) "Pollution" means the man-made, man-induced, or natural alteration of the physical, chemical, biological, and radiological integrity of water.

(l) "Subsurface" means any level below the surface of the land.

(m) "Subsurface disposal system" means any system or facility, method, excavation, well structure or condition of any kind whatsoever (other than individual sewage disposal systems, solid waste disposal sites, sanitary landfills, refuse disposal sites, oil and gas wells, water injection wells employed in oil and gas well operations, surface ditches or retention ponds and irrigation and water transportation systems), used, employed or operated so that the same may reasonably be expected, by direct or indirect means, to result in the disposal of wastes underground, including without limitation, the following: Sewage systems, treatment works, wells into which wastes are deposited or injected, installations, structures, wells and excavations to be used in connection with any subsurface explosion, detonation, reaction or process that might tend to discharge, deposit or generate wastes underground, and mines or other excavations initially made for other purposes when they are used for disposal.

(n) "Subsurface water" or "Groundwater" means any waters of the State not visible on the surface of the ground under natural conditions.

(o) "System" means all surface and subsurface equipment, installations and appurtenances and shall include the formations within the zone of influence of a subsurface disposal system.

(p) "Waste" means any substance, solid, liquid or gaseous, including radioactive particles thereof, which pollute or may tend to pollute any waters of the State.

(q) "Workover" means any remedial procedure which could change the physical or chemical characteristics of the formation, or changes in physical equipment (other than routine maintenance of mechanical equipment), repairing or replacing casings, tubing, packing and plugging or perforating additional zones.

(r) "Zone of influence" means the areal extent to which a waste can or will migrate or be dispersed within a stated period of time from a subsurface disposal system, as well as the areal extent of the significant variations of formation fluids caused by such a system.

Section 3 - PREREQUISITES TO CONSTRUCTION AND OPERATION OF SUBSURFACE DISPOSAL SYSTEMS.

(a) No person shall construct or operate a subsurface disposal system within the State of Colorado unless such person has a currently effective permit for such construction or operation issued by the Division pursuant to this Section.

(b) No person shall receive a permit from the Division for the construction or operation of a subsurface disposal system within the State of Colorado unless the Commission, acting upon the application of a person proposing to construct or operate a subsurface disposal system shall have found and determined beyond a notice and public hearing, one of the following:

(1) that no waters of the State will be polluted thereby; or

(2) that if waters of the State may be polluted thereby, the pollution resulting therefrom will be limited to waters in a specified limited area from which there is no risk or significant migration and the proposed activity is justified by the public need.

Any other finding by the Commission shall preclude the construction or operation of a subsurface disposal system at the site proposed in the application in response to which the Commission has made its findings.

(c) Every finding by the Commission under the provisions of subparagraph (b) of this Section shall be stated in writing, refer to the application upon which it was based, and shall be final; provided, however, the Commission will grant a rehearing to an applicant requesting the same if good cause therefore be shown to the Commission and such request is made within 30 days after the date of the entry of the Commission's findings. Any person assuming to construct and/or operate a subsurface disposal system, with or without a permit issued by the Division, shall be solely responsible for such system and shall be deemed to have assumed all risks in respect to the construction and operation of such system.

(d) When the Commission shall have, pursuant to application, made one of the findings described in subparagraphs (1) or (2) of subsection (b) of this Section, the Division shall grant to the applicant a permit to construct, operate or construct and operate, as the case may be, the subsurface disposal system for which the application has been made, which permit may be subject to any conditions reasonably required by the Division.

(e) Any person having applied to and received from the Division a permit under the provisions of this Section and thereafter assuming to construct and/or operate a subsurface disposal system under the permit shall be subject always to such orders and regulations as the Division may reasonably require, from time to time, for the prevention, abatement and control of pollution to the waters of the State, including but not limited to one or more of the following:

(1) that no zone or interval, other than the zone or interval represented to both the Commission and Division as the disposal interval or aquifer, shall be used as part of the system except after notice and hearing.

(2) that a monitoring system, including prescribed equipment, tests, and installations, shall be provided and operated at the sole risk, cost and expense of the persons interested in the system; provided, however, the Division may designate some third party to utilize the monitoring system data developed by or for the operation of the system.

(3) that treatment of wastes shall be provided to that degree required by the Division.

(4) that workover or remedial procedures shall not be performed without prior notification of the Division and then only to the extent ordered by the Division.

(5) that disposal shall be only in such manner as may be ordered by the Division in respect to volume, rate, pressure, and similar parameters and shall not exceed that specified or be of a kind different from that presented to both the Division and the Commission upon the application filed under the provisions of Section 4 of these Rules.

(6) that all drilling, completing, and operating procedures for subsurface disposal and monitoring systems or wells shall conform to those practices and procedures previously reviewed by the Division and that any deviation in procedure or equipment from that specified in the applications presented to the Division shall require the concurrence of the Division before deviation from such procedures may be implemented.

(7) that an adequate back-up facility be provided, including surface equipment, pumps, well-head,

transmission lines, holding tanks, retention ponds and treatment facilities, to assure that a system may be safely shut down in the event of component failure and to assure the treatment of effluent to a suitable degree for temporary surface disposal.

(8) that evidence of financial responsibility be submitted to the Division and, when the Division so requires by its order, security, in the form of cash, approved securities, surety bond, or evidence of insurance, be deposited with the Treasurer of the State of Colorado, in such amount and with and under such conditions as the Division may direct to assure the people of the State of Colorado of the continued compliance with the Division's orders and that, upon abandonment, cessation or interruption of the construction or operation of the system, appropriate measures will be taken to prevent present or future pollution of the beneficially usable waters of the State. Whenever evidence of financial responsibility is required, such evidence shall be furnished annually for as long as the Division may require.

(9) that the Division shall be furnished with such reports, charts, forms, and other information as it may reasonably require and at such intervals as may be directed by the Division from time to time.

(10) that notwithstanding any prior finding, order or permit of the Division the continued or future construction of operation or use of a disposal system shall, upon order of the Division, be discontinued after notice and hearing if the Division determines that continued operation thereof is or may tend to be injurious to the then present or foreseeably beneficially usable waters of the State.

Section 4 - APPLICATION FILED WITH DIVISION. - Any person proposing to construct or operate, or cause to be constructed or operated, a subsurface disposal system within the State of

Colorado shall file with the Division a verified, written application for a permit under Section 3 of these Rules. Such application shall contain, unless the requirement is waived as inapplicable by an order of the Division, the following:

(a) A legal description of the area within a radius of two (2) miles of the proposed system and a legal description of the site upon which the system will be located.

(b) An accurate map of the area within a two (2) mile radius of the proposed system showing the location of the system, property boundaries, surface and mineral ownership of record, the location of all water wells and oil and gas wells and whether the same are operating or have been abandoned and, if appropriate, whether such wells have been plugged; and the location of all mines, test holes and other artificial penetrations or excavations.

(c) A description of the depths and deepest formations penetrated by each of the wells, mines, excavations or penetrations required to be shown on the map required at (b) above.

(d) A description of local topography, industry, agriculture, population densities, culture, wildlife, and fish and other aquatic life within the area of the proposed system with a projection as to the probable effect of the system upon industry, agriculture, population, culture, wildlife, and fish and other aquatic life.

(e) A description of the mineral resources believed to be present in the area of the system and the probable effect of the system upon such mineral resources, together with a map or maps illustrating geologic structures and stratigraphic sections (formations, lithologies and physical characteristics for the local area and a general map illustrating the regional geologic setting of the system). Such exhibits shall be prepared by a qualified expert.

(f) A description of all water resources, both surface and subsurface, within the probable zone of the influence of the system, the classification if any, the available amounts thereof and potential uses and a map or maps indicating vertical and lateral limits of surface and subsurface water supplies.

(g) A description of the chemical, physical, radiological and biological properties and characteristics of the wastes to be disposed of through the system, and the treatment proposed for such wastes.

(h) Copies of all plans and specifications for the system and its appurtenances.

(i) A statement of all sources relied upon for the information set forth in the application.

(j) If the disposal system is to be an injection well, the following information shall be required:

(1) Potentiometric surface maps of the disposal aquifers and those aquifers immediately above and below the disposal aquifer.

(2) Copies of all drill-stem tests, extrapolations and data used in making the maps required at (1) above.

(3) Location and nature of present and potential use of fluids from the disposal or affected aquifer formations in the general area.

(4) Volume, rate and injection pressure of the fluid to be injected.

(5) The following geologic and physical characteristics of the injection interval and the overlying and underlying impermeable barriers:

(aa) Thickness.

(bb) Areal extent.

(cc) Lithology (grain mineralogy, type and mineralogy of matrix, amount and type of cement, clay content, clay mineralogy).

(dd) Effective porosity and how determined.

(ee) Permeability, vertical and horizontal, and how determined, i.e., mechanical (electrical) logs, core analyses, formation tests.

(ff) Coefficient of storage of aquifer.

(gg) Amount and extent of natural fracturing.

(hh) Location, extent and effects of known or suspected faulting.

(ii) Extent and effects of natural solution channels.

(jj) Fluid saturation.

(kk) Formation fluid chemistry with indications of local and regional variations.

(ll) Temperature of formation and how determined.

(mm) Formation and fluid pressures, original and modifications resulting from previous fluid withdrawals.

(nn) Fracturing gradients.

(oo) Osmotic characteristics of rock and fluids both comprising and contiguous to the reservoir, and an indication of the effect of injected wastes on contiguous formations in the event of leakage.

(pp) Diffusion and dispersion characteristics of the waste and formation fluid, including effect of gravity segregation.

(qq) Compatibility of injected waste with physical, chemical and biological characteristics of the reservoir.

(6) The following engineering data concerning the well:

(aa) Size of hole and estimated total depth of well.

(bb) Type, size, weight, strength, and related data in respect to all surface, intermediate and production casing.

(cc) Specifications and proposed installation of tubing and packers.

(dd) Proposed cementing procedures and type of cement.

(ee) Proposed coring program.

(ff) Proposed information testing program.

(gg) Proposed injection procedure, i.e., open hole, perforated casing.

(7) Plans for monitoring the system and, if the system is a deep disposal well, the plans for monitoring injection pressures and formation pressures, i.e., injection wells and observation wells.

(8) Expected changes in pressure, rate of fluid displacement by injected wastes, directions of dispersion and area affected by the system.

(k) Such other and further data as the Division may reasonably request. An applicant may upon its own initiative, or shall when requested by the Division, furnish an opinion of independent experts, satisfactory to both the Division and Commission, in respect to the accuracy and completeness of any information or data furnished by the applicant and on any aspect of the applicant's disposal system or the contemplated operation or effects thereof.

Section 5 - PRELIMINARY REVIEW OF APPLICATIONS

(a) The Commission and the Division recognize that the accumulation of the information and data required to complete an application under Section 4 of these Rules may involve considerable expense to an applicant. Therefore, and merely as a convenience to applicants, the Division will accept for preliminary review applications setting forth in general terms the information specified in Section 4, but the same shall be set out in sufficient detail so as to enable the Division to determine the general feasibility of a proposed system. Such applications shall be clearly designated as "for preliminary review" under authority of this Section.

(b) The Division may rule upon applications submitted for preliminary review and either approve or disapprove the feasibility of the proposed system. The approval or disapproval by the Division upon preliminary review of applications shall in no way affect the right of an applicant to subsequently submit an application or applications containing the data required by Section 4 of these Rules. Neither the Commission nor the Division shall be bound by any ruling upon any application submitted for preliminary review.

Section 6 - PROCEEDINGS BEFORE THE COMMISSION - NOTICE - PUBLIC HEARING.

(a) Before any finding upon an application, or application for rehearing, or finding, or amendment of a finding shall be made by the Commission under these Rules, there shall be held a public hearing upon at least twenty (20) days notice at such time and place as may be prescribed by the Commission and any person interested in the action of the Commission shall be entitled to appear and be heard; except, when an emergency requiring immediate action is found to exist by the Commission, the Commission may issue an emergency order without notification of the hearing, which shall be effective upon promulgation, but shall remain effective for no more than twenty (20) days.

(b) The Applicant shall cause notice of every public hearing to be given by personal service to each surface and mineral owner of record within a two (2) mile radius of any subsurface disposal system which may be the subject of any proceeding before the Commission, or it may give such notice by one publication in a newspaper of general circulation in the City and County of Denver, Denver, Colorado, and in a newspaper of general circulation in the county where the land affected by a subsurface disposal system, or some part thereof, is situated. Said notice shall be issued in the name of the State of Colorado, shall be signed by the Commission, or the Technical Secretary of the Commission, and shall specify the style and number of the proceedings, the time and place of the hearing, and shall briefly state the purpose of the proceeding.

(c) If notice is given by personal service, such service shall be made by an officer appointed to serve summons, or by an agent of the Commission, in the same manner and extent as is provided by law for the service of summons in civil actions in the District Courts of this State. Proof of service by such agent shall be by his affidavit and proof of service by any officer shall be in the form required by law with respect to service of summons in civil actions.

(d) In addition to the notice required to be given under subparagraph (b) of this Section, notice of every application filed with the Commission shall be given by the applicant by mailing or delivering a copy of the application to each surface and mineral owner of record within two (2) miles of any proposed subsurface disposal system. Such notice shall be mailed or delivered on or before the date the application is filed with the Commission. An affidavit shall be attached to the application showing the parties to whom the notice required by this subsection has been served, and their respective addresses.

(e) The Commission shall designate a hearing officer, as provided in the Act, who shall make findings and recommendations to the Commission in respect to any matter pertaining to a subsurface disposal system.

(f) Either the Commission or the Division may, on its own motion, or upon the request of any interested person, institute a proceeding to prevent a violation of the Act, or of any order, rule or regulation of the Commission or permit issued by the Commission or the Division relating to a subsurface disposal system, or for the amendment of any order, rule or regulation, by notice of hearing, or issuance of an emergency order to show cause directed to and served upon any person or persons charged with violating the same, and may take any step allowed under law.

(g) Hearings before the Commission shall be conducted without rigid formality. A transcript of testimony shall be taken and preserved as part of the permanent record of the Commission. Any person testifying before the Commission or in support of an application or in opposition thereto shall be required to do so under oath or affirmation. Full opportunity shall be afforded all interested parties at a hearing to present evidence and to cross-examine witnesses. In general, the rules of evidence applicable before a trial court without a jury shall be applicable, providing that such rules may be relaxed, where by so doing, the ends of justice will be better served.

Section 7 - TERMINATION, ABANDONMENT. - No Subsurface disposal system subject to these Rules shall be terminated or plugged and abandoned except after notice and hearing. Every plugging and abandonment shall be accomplished in accordance with the orders of the Division. Monitoring equipment shall be operated and precautionary steps shall be undertaken after termination or abandonment for as long as the Division may reasonably require, which operation and steps shall be at the sole risk, cost, and expense of the person responsible for the disposal system.

Section 8 - WAIVER OF BASIC STANDARDS. - Any person operating a subsurface disposal system under an effective permit issued pursuant to these Rules shall not, as a result of the discharge from that system, be deemed to be in violation of the Basic Standards applicable to all the waters of this State.

Section 9 - OTHER REGULATORY AGENCIES. - Nothing in these Rules shall relieve a person making application to the Commission and Division from complying with all applicable rules and regulations of other government agencies, whether State or Federal.

Section 10 - RESPONSIBILITY. - Compliance with the Rules contained herein shall in no way be deemed to relieve any person of any liability, obligation or duty imposed on such person by statute or the common law.

Section 11 - RELIANCE UPON OTHER AGENCIES. - The Commission and the Division of Administration shall freely consult with such other State and Federal agencies and departments as the Division of Administration or the Commission may deem necessary for a proper determination of any matter subject to these Rules. Notice of hearing before the Commission or before a hearing officer designated by the Commission shall be given to interested State and Federal agencies and departments.

Section 12 - AUTHORITY. - These Rules are promulgated pursuant to the authority conferred upon the Commission by the Water Quality Control Act of 1973 (C.R.S. 66-28 as amended) and by C.R.S. (1963) 3-16-2 (6) as amended.

Florida[1]

The state agency having the primary responsibility for regulating disposal wells is the Florida Department of Health and Rehabilitation Services Division of Health (formerly known as the State Board of Health). The Florida Air and Water Pollution Control Authority will have a responsibility on the future use of underground disposal systems in Florida. They are presently considering a policy encouraging that type system for liquid wastes whenever geohydrologic conditions are favorable.

Georgia[1]

The State Water Quality Control Board has the responsibility for establishing policy and regulating water pollution control over all waters of the State (Act No. 870, as amended).

The technical staff for the Board is the Division for Georgia Water Quality Control created within the Health Department. Any applications for permits or approval of subsurface disposal would have to be processed by the Board. Also, it is quite likely that an interagency approach would be used in the processing of applications. Although there are no specific statements directly relative to subsurface disposal, the Board, under the statute does have authority to adopt whatever rules and regulations it should deem necessary should such a proposal be made.

The present policies regarding subsurface disposal of industrial wastes are that it is generally not an accepted method and that any such storage should be approached with great caution. Criteria and regulations are being developed for deep-well disposal.

Idaho[1]

The regulating agencies charged with the protection of fresh waters are:

A. State Board of Health (39-101 (4)) Idaho Code.

B. Water Resources Board of the Department of Reclamation (42-1734) Idaho Code.

In all probability should deep-well disposal be utilized this state would also have an interagency approach and the Bureau of Mines and Geology would be directly involved.

Illinois[1,2]

A divided authority exists between Sanitary Water Board and the Department of Mines and Minerals.

A. Rule IX under the Department of Mines and Minerals for the Oil and Gas Division.

  1. Disposal in Underground Stratum.

     Salt water or other waste liquids may be disposed of into an underground formation or strata after a permit to do so has been procured from the Mining Board as hereinbefore provided. The Mining Board shall have the authority to designate and approve the stratum into which such liquids shall be disposed of, also the protective work necessary to confine such liquids to the intended stratum. All such work shall be executed under the supervision of a Mining Board Representative and shall conform to the requirements imposed in granting the permit therefore.

H.B. 416, Sec. 86 (passed at 1967 session of the Legislature) specifies that well for injection gas, oil, water, or other liquid -- requires permit from Mining Board. Also that Mining Board may prescribe rules and regulations -- in connection with such wells.

B. Statute Creating Sanitary Water Board (1929, superseded by 1951 Act).

1. Ill. revised Stat. C-19 Sections 145-1 to 145-18. Pollution of waters of the state is not allowed. Sanitary Water Board can determine whether pollution exists; issue permits for waste discharge installations into waters of the state.

Administrative and Technical Procedures controlling the installation and operation of deep-well injection of industrial waste in Illinois.

Administrative Procedures -

Basis of Requiring Sanitary Water Board Permit: Sanitary Water Board Act requires a permit be obtained from the Board before the construction or use of any new outlet for the discharge of any wastes into the waters of the State. The waters of the State are defined as follows: ...."Waters of the State" means all accumulations of water, surface and underground, natural or artificial, public or private or parts thereof, which are wholly or partially within, flow through, or border upon this State or within its jurisdiction."....

There is also authorization in the Act for the Board to prescribe the requirements to be met before the issuance of a permit for a particular facility such as the submission of such plans, specifications, and other information as it deems relevant and necessary.

General Procedures Followed -

The interested industry must have prepared a comprehensive Feasibility Report and submit it to the Technical Secretary for review, comment and receive tentative approval subject to the receipt of final construction documents for the proposed test well. Upon receipt of several copies of the Feasibility Report, the Illinois State Water Survey, the Illinois Geological Survey and the Department of Mines and Minerals are requested to review the report and report their opinions, recommendations and questions to the Technical Secretary of the Board. Also, the technical engineering staff of the Bureau of Stream Pollution Control and Bureau of Public Water Supplies review the Feasibility Report.

If and when tentative approval is given by the Technical Secretary, then the Industry must prepare proposed final construction and testing procedure plans and specifications prior to the drilling of the test hole. Again, the above noted agencies give a technical review of these documents and forward their advisory comments to the Technical Secretary. When the proposed final construction and testing plans and specifications are satisfactory, the Technical Secretary issues a letter of approval to proceed with the drilling of the test well as the next step toward obtaining a permit to install and operate a deep disposal well.

During the drilling of the test well, in accordance with the previously approved procedures, engineering and geological personnel make field observations of various tests performed at the well, such as logging, rock core sampling, formation fluid sampling, and injection tests. The Industry is required, as set forth in their approved procedures, to notify the Technical Secretary of the upcoming testing to be done, several hours ahead of time so that the appropriate personnel may be present. The State personnel are prepared to proceed without delay to the site so as not to cause expensive delay in the drilling of the test hole. Also, the State personnel are prepared to make field decisions as necessary which are confirmed by letter immediately thereafter.

When the test hole is completed and the necessary test data is completed, the Industry must then submit the data and proposed final construction plan documents as modified on the basis of test results, to the Technical Secretary for review. The above State agencies are again asked to review the test data. If the modified final plans are satisfactory, then a permit to install and operate the well casing and surface works is issued.

It should be noted that we do hold conferences with the industry and other State agencies before the submission of the Feasibility Report. Other conferences are encouraged and held as necessary during the development of the plan documents and the drilling of the test hole to help insure effective current communication between the State and the industry on all details of the project.

Technical Considerations of Deep Well Disposal -

The basic policies are as follows:

(1) All zones to be considered for disposal must contain brine waters having over 10,000 mg/l total dissolved solids. This equates to a one percent solution of total dissolved solids.

(2) There must be an effective and adequate impermeable barrier overlying the disposal zone to prevent upward migration of either the wastes or displaced brine waters into fresh water zones.

(3) The well bore must be double cased and the annular spaces grouted to a point 200 feet below the lowest fresh water zone. The outer casing is to be set into the next lower suitable rock barrier.

(4) Fresh water is defined as water of 10,000 mg/l or less total dissolved solids. A figure of 5,000 mg/l or less had been used until recently to define fresh

water. This was revised upward to preserve ground waters that may be usable if and when current experimental methods of desalination are made practical for the production of potable water from brackish waters.

(5) The industry must indicate the character and volume of waters to be injected into the deep well. Compatibility of the wastes with the formation fluids must be indicated.

(6) Operational injection pressures to be used must be indicated in the plan documents. We have not permitted injection pressures that cause fracturing of the rock formations in the injection zone.

(7) Detailed information about the proposed surface injection equipment must be provided as a part of the plan documents.

(8) The industry is required as a condition of the permit to submit daily injection report records each month to the Sanitary Water Board. These operating reports must include the character and volume of the waste and show the injection pressures.

(9) We are currently reviewing the necessity for requiring the installation of observation wells to detect the escape of any fluids from the disposal zone.

General Consideration of Deep Well Disposal of Industrial Wastes -

We consider that this procedure is relatively new to Illinois. It is realized that any pollution of any underground potable or fresh waters will undoubtedly represent a long-term damage to a critical natural resource. It is believed and hoped that the procedures governing the installation and operation of deep disposal wells are conservative. If we err in engineering and administrative judgment, it is hoped that it be toward the conservative side of the scale so that the critical natural resource of underground waters is conserved for present and future use. It is intended that the administrative and technical reviewing procedurew preparatory to the issuance of a Sanitary Water Board permit to install and operate a deep disposal well, be rigorous -- even more so than for a permit to install and operate treatment facilities for a surface discharge where the necessity of corrective measures are more easily observed and accomplished.

Indiana[1,2]

Indiana has been utilizing subsurface disposal of industrial waste to a limited extent since 1951. Jurisdiction over subsurface disposal of industrial wastes in Indiana rests with the Indiana Stream Pollution Control Board. The Stream Pollution Control Board was created by Chapter 214, Acts of 1943 of the Indiana General Assembly. All projects for subsurface disposal of waste waters other than those resulting from oil and gas operations are required to be submitted to the Stream Pollution Control Board for review and approval in accordance with Section 10 of Chapter 214. Section 10 reads in its entirety that "all plans and specifications for abatement or correction of any polluted condition shall be approved by the Stream Pollution Control Board. The Stream Pollution Control Board shall advise and consult, on request, with any person planning any correction or prevention of any pollution condition of any waters of this State".

Section 6 of Chapter 214 indicates the Stream Pollution Control Board shall have the power to call upon any state offices, boards, departments, schools, universities or other state institutions, and the officers or employees thereof, and receive any assistance deemed necessary to the carrying out of the provisions of this Act. Much of the day-to-day work of the Board is effected by the Indiana State Board of Health. The Indiana Department of Natural Resources commonly provides technical counsel to the Board; usually the Geological Survey of the Indiana Department of Natural Resources provides judgment as to feasibility when projects for subsurface disposal of industrial wastes are proposed.

Indiana also has a relatively new law that, among other things, pertains to "test holes for, or in connection with, fluid disposal investigation". This law is administered by the Indiana Department of Natural Resources, parent of the

Geological Survey. Current interpretation of the law is that if one proposing to drill a disposal well takes the position that disposal feasibility has been established, there is no need for investigation and the law does not apply. This current interpretation will undoubtedly limit the usefulness of the law.

Accordingly, total jurisdiction over industrial waste disposal systems continues to rest with the Indiana Stream Pollution Control Board. The body has issued no new policy statements. Also, there is some question whether any standard forms are being used in processing these wells other than those the operating companies submit.

Kansas[1,5]

Primary control over the subsurface disposal of industrial and municipal wastes rest with the State Department of Health. Their authority is derived from the General Statutes of Kansas (KSA 65-161 through 65-171h, as amended). The State Corporation Commission shares the responsibility of oil and gas field brine disposal with the Health Department (KSA 55-1003). The Board of Water Resources and the Geological Survey (KSA 55-1006) also have certain responsibilities in selecting the proper zone in which to dispose waste.

KSA 65-171d as amended by Sec. 4, HB 1497, 1967 Session: "For the purpose of preventing surface and subsurface water pollution and soil pollution detrimental to public health or to the plant, animal, and aquatic life of the state, and to protect beneficial uses of the waters of the State, the State Board of Health shall make such rules and regulations including registration of potential sources of pollution, as may in its judgment be necessary to protect the waters of the state from pollution by oil, gas, salt water injection wells, or underground storage reservoirs; to control the disposal, discharge or escape of sewage as defined in KSA 65-164, by or from municipalities, corporations, companies, institutions, state agencies, federal agencies, or individuals and any plants, works, or facilities owned and/or operated by them; and to establish water quality standards for the waters of the state to protect their beneficial uses. For the purposes of this act, and if not otherwise included, including KSA 65-161 through 65-171h, pollution is hereby defined as such contamination or other alteration of the physical, chemical or biological properties of any waters of the state as will or is likely to create a nuisance or render such waters harmful, detrimental, or injurious to public health, safety or welfare, or to the plant, animal, or aquatic life of the state, or to other legitimate beneficial uses. In making rules and regulations, the state board of health, taking into account the varying conditions that are probable for each source of sewage and its possible place of disposal, discharge, or escape, may provide for varying the control measures required in each case to those it finds to be necessary to prevent pollution and protect the beneficial uses of the waters of the State. The storage or disposal of salt water, oil or refuse in surface ponds shall be prohibited unless a permit for such storage or disposal shall first be obtained from the State Board of Health, and such permit shall be considered as granted unless denied within ten (10) days. The State Board of Health is authorized to deny or revoke a permit for such storage or disposal in any case where it finds such storage is causing or likely to cause pollution: Provided however, that surface ponds in use on the effective date of this act may be operated without a permit until January 1, 1958.

"Whenever the board or its duly authorized agents shall find that the waters of the state are not being protected from pollution by oil, gas, salt water injection wells, or underground storage reservoirs, or that storage or disposal of salt water, oil or refuse in any surface pond is causing or is likely to cause pollution of waters of the state, or soil detrimental to public health, plant, animal or aquatic life, the executive secretary or duly authorized agents designated by him, shall issue an order prohibiting the operation or use of such oil, gas, salt water injection well, underground storage reservoir, or surface pond; such order to take effect ten (10) days after service upon the owner, operator, contractor, or agents thereof. Any person aggrieved by such order may within ten (10) days of service of the order request a hearing on the order.

"Hearings may be conducted by the board, executive secretary, or hearing officers appointed by the executive secretary. Such hearing officers shall have the power and authority to conduct such hearings in the name of the board at any time and place. A record of the proceedings of such hearings shall be taken and filed with the board together with findings of facts and conclusions made by the board. On the basis of the evidence produced at the hearing, the board shall make findings of fact and conclusions of law and shall give written notice of such findings and conclusions to the alleged violator. The order of the board shall be final unless appealed to the courts within thirty (30) days after the order has been made.

"Any notice, order or instrument issued by or with the authority of the board may be made by mailing a copy of the notice, order, or other instrument by registered or certified mail directly to the person affected at his last known post-office address as shown by the files or records of the board.

"An appeal may be taken from any final order or final determination of the board by any person adversely affected, to the district court of the county of residence of the appellant. Notice of appeal from any such final order or determination shall be served on the board through its executive secretary. Failure to serve such notice of appeal within thirty (30) days shall operate as a waiver of the right of appeal. Notice of appeal shall refer to the action of the board appealed from and shall specify the grounds for appeal. Copy of the original notice of appeal with proof of service on the executive secretary shall be filed by the appellant with the clerk of the court within ten (10) days of the service of the notice and thereupon the court shall have jurisdiction of the appeal. Service of a notice of appeal shall not operate as a stay of the board order; however, the appellant has the right to apply to the board for a stay, which the board in its discretion may grant. Upon receipt by the executive secretary of the notice of appeal, he shall, within fifteen (15) days, file with the clerk of the district court a certified transcript of all files and proceedings relating to the order or decision appealed from. The review shall be conducted by the court without a jury and shall be de novo, except that in cases of alleged irregularities in procedure, testimony thereon may be taken in the court. The court may affirm the order or decision of the board, or may reverse or modify said order. Appeals may be taken to the supreme court from the order or decision of the district court in the same manner as in other civil cases. The Board of Health shall fix fees to cover the cost of services rendered under this act."

New regulations for disposal wells are to be formulated pursuant to the 1967 amendments to the existing act. The following excerpts are from the regulations that existed prior to the 1967 amendments.

Article 13. Underground Storage, Disposal Wells and Surface Ponds

"28-13-1. SCOPE. This article regulates the construction and use of underground storage reservoirs and the construction and use of disposal wells and surface ponds for the confinement, storage and disposal of industrial fluids including but not limited to brines, but does not include regulations pertaining to oil field activities described in L 1965, ch. 506, Sec. 1(4). (Authorized by K.S.A. 65-164, 65-165, 65-171d; compiled January 1, 1966).

"28-13-2. DEFINITIONS.

C. Disposal Well. The term disposal well as used herein is defined as any well which receives industrial waste waters, both organic and inorganic, salt water or other highly mineralized waters for disposal into underground formations. (Authorized by K.S.A. 65-164, 65-165, 65-171d; compiled January 1, 1966).

"28-13-10. PERMITS REQUIRED FOR DISPOSAL WELLS. The use of any disposal well not otherwise exempted by these regulations shall be prohibited unless a permit for such disposal well shall first have been obtained from the State Department of Health. (Authorized by K.S.A. 65-164, 65-165, 65-171d; compiled January 1, 1966).

"28-13-11. APPLICATIONS FOR DISPOSAL WELL PERMITS. Applications for permits for disposal wells shall be submitted in duplicate to the chief engineer for the State Board of

Health on forms obtainable from his office. Applicant shall supply such other information, plans and specifications as may be needed to adequately review the project. (Authorized by K.S.A. 65-164, 65-165, 65-171d; compiled January 1, 1966)."

Kentucky[1,7]

Any application for a waste disposal project in Kentucky goes to the Water Pollution Control Commission of the Kentucky Department of Health, Division of Environmental Health. The burden of proof of feasibility is on the applicant. The Commission has their own petroleum engineer; however, they obtain advice from the Kentucky Geological Survey and the Division of Oil and Gas, Kentucky Department of Mines and Minerals. Although no specific regulations have been adopted by this Commission, the following requirements for the disposal of wastes into the subsurface would have to be submitted in support of an application before issuance of a permit.

1. A process "flow sheet" and description of the plant's operations.

2. A detailed explanation of the plant's operations which result in a waste effluent.

3. A breakdown of the substances and quantities that will be contained in the waste stream.

4. A geological report describing the local and regional geology. If possible, the zone of influence of the well must be defined.

5. Information on wells previously drilled in the influence zone, their location and condition.

6. The storage capacity of the disposal formation, the maximum injection rates and pressure.

7. Information regarding the treatment facilities required to render the waste waters compatible with the disposal formation waters.

8. Type of monitoring system or systems that will be provided.

9. A plan showing a standby or alternate disposal system.

10. The type of construction which will be applicable to completion of the disposal well.

In addition to the above supporting information the Commission requires a copy of the permit or authority to drill the well obtainable from the Division of Oil and Gas. Performance bonds would be required for the life of the well.

Louisiana[1,6,7]

There are three agencies which have laws governing industrial wastes. These are the Department of Conservation, State Board of Health, and the Louisiana Stream Control Commission. Of the three, the first two are in a more authoritative position with respect to the subsurface disposal of industrial wastes and permits have to be obtained from both departments.

Drilling methods and operating procedures for industrial waste disposal wells have generally followed those developed by the Department of Conservation for underground disposal of oil field brines. Disposal of these brines by underground injection has been employed for many years prior to industrial waste injection and has been very successful in Louisiana.

The history of successful operations of oil field brine disposal influenced the state authorities to permit underground disposal of industrial waste.

Salt Water Disposal -

The Louisiana Department of Conservation has the responsibility of protecting fresh water sands from contamination by oil, gas, and salt water. The authority for this protection is contained in Title 30, Chapter 1, Section 4, Paragraph C of the Louisiana Revised Statutes of 1950 which reads:

"The Commissioner of Conservation has authority to make after notice and hearing as provided in this Chapter, any reasonable rules, regulations, and orders that are necessary from time to time in the proper administration and enforcement of this Chapter, including rules, regulations or orders for the following purposes:

(i) To require the drilling, casing, and plugging of wells to be done in such a manner as to prevent the escape of oil or gas out of one stratum to another, to prevent the intrusion of water into oil or gas strata; to prevent the pollution of fresh water supplies by oil, gas, or salt water; and to require reasonable bond with security for the performance of the duty to plug each dry or abandoned well."

Statewide Order 29-B issued by the Department of Conservation July 19, 1943, and subsequent amendments govern the drilling for and the producing and plugging of oil and gas wells in Louisiana. This order has definite provision for preventing pollution of underground fresh water supplies. Section XV of Statewide Order 29-B regulates the production and disposal of salt water.

This section states:

"When a well starts to produce salt water, the operator or company shall report that condition to the Department. Permits must be secured before disposing of salt water underground."

The Department also requires that the salt water be injected into a sand which carries salt water and that the injected water will not displace any fresh water up gradient or be put in a sand which produces oil and gas. Fresh water sands which are drilled through must be protected by an adequate casing and cementing program. These provisions also apply to industrial wastes.

As stated in the Amendment to Statewide Order 29-B, dated October 19, 1967:

(1) No waste oil or oil field waste shall be disposed of into any stream, lake or other body of water or into any ditch or surface drainage depression leading to any stream, lake or other body of water. Such waste shall be retained for proper disposal.

(2) Produced salt water shall be disposed of into subsurface formations not productive of hydrocarbons, except:

(a) It may be disposed of in pits where such method and pits have been approved by the Commissioner of Conservation.

(b) It may be disposed of in tidally effected waters, brackish water or any other waters unsuitable for human consumption or agricultural purposes.

(3) Producing salt water shall not be disposed of into a zone producing or productive of hydrocarbons unless such disposal is approved by the Commissioner of Conservation after a public hearing or unless prior approval has been granted to use the proposed zone for salt water disposal.

The Commissioner of Conservation shall cause an inspection to be made of each completed disposal facility to insure compliance with this Amendment.

A reasonable estimate of the amount of salt water injected annually into each disposal well shall be reported to the Geological Oil & Gas Division with a copy to the appropriate District Manager, such report to be filed during the first quarter of the next calendar year.

Amendment to Statewide Order 29-B dated February 27, 1974, Section XIX F-3 c and d pertains to abandonment procedures and states:

(c) When production casing is not run or is removed from the well, a cement plug of at least one hundred feet (100') shall be placed from at least fifty feet (50') below the shoe of the surface casing to at least fifty feet (50') above. In lieu of the above, the operator shall have the option of using a cement retainer placed at least fifty feet (50') above the surface casing shoe and a sufficient amount of cement shall be squeezed below the retainer to form a cement plug from the base of the retainer to fifty feet (50') below the base of the surface casing. A ten foot (10') cement plug shall be placed on top of the retainer.

(d) If fresh water horizons are exposed when production casing is removed from the well, or as a result of production casing not being run, a cement plug shall be placed from at least one hundred feet (100') below the base of the deepest fresh water sand to at least one hundred fifty feet (150') above the base of the sand. A cement plug of at least one hundred feet (100') shall also be placed from at least fifty feet (50') below the shoe of the surface casing to at least fifty feet (50') above it. In lieu of the above, the operator shall have the option of using a cement retainer placed at least fifty feet (50') above the surface casing shoe and a sufficient amount of cement shall be squeezed below the retainer to form a cement plug from the base of the retainer to fifty feet (50') below the base of the surface casing. A ten foot (10') cement plug shall be placed on top of the retainer.

Industrial Waste Disposal -

The Department of Conservation has the same responsibility in the protection of subsurface fresh water sands in the case of industrial waste disposal wells as with salt water disposal wells, with the same provisions of Title 30 being applicable.

The approval, procedure and requirements for industrial waste disposal wells as of June 1974 follow:

1. Application will be filed in duplicate with the District Office. In addition, an application is to be filed with

the Louisiana Department of Health for their approval. Applications should include the following:

a. A plat showing the location, or proposed location, of the well.

b. An electrical log of a nearby well showing the proposed disposal zone with the approximate depth indicated.

c. A schematic diagram showing the proposed casing depths, cement program, and packer depths if packer is to be used.

d. Daily volume of waste to be injected (in barrels).

e. Analysis, or constituents, of proposed waste stream.

f. Casing and cementing requirements are:

SURFACE CASING - To be set through and below fresh and brackish water sands and cemented back to the surface.

SECOND STRING - To be set below the minimum depth allowed (depending on area) for waste injection and cemented back to the surface.

THIRD STRING - To be set to and/or through the disposal zone and cemented back to the surface.

ALTERNATE:

SURFACE CASING - To be set through and below fresh and brackish water sands and cemented back to the surface.

LONG STRING - To be set to and/or through the disposal zone and cemented back to surface.

TUBING - To be run and set on a packer. The packer is to be set below the minimum depth allowed for waste disposal.

2. The application will be first processed by the District Office and, if satisfactory, a copy of the above listed data will be forwarded to the Geological Oil & Gas Division.

3. The Geological Oil & Gas Division will then review the application with regard to depths for setting casing, etc. The letter will be sent to the District Manager indicating approval or denial and reason for denial of the application.

   NOTE: When a proposal is approved, final approval for completion of the well in the injection sand is given upon receipt and review of the electrical log of the waste disposal well and the casing program with packer setting depth if utilized.

4. Upon receipt of the Geological Oil & Gas Division's letter, the District Manager shall notify the applicant of approval or denial of the application and reasons for denial.

5. Once the disposal well is in operation, the following shall be required January 1 and July 1 of each year:

   a. Average amount of waste injected daily in barrels.

   b. Total amount of waste injected in the six (6) month period (barrels).

   c. Cumulative total of injected waste (barrels).

   d. Chemical composition of waste.

6. Form WH shall be filed upon completion of the well. Prior approval shall be secured before a disposal well is recompleted and after recompletion, Form WH shall be filed to indicate the work performed.

7. Prior to abandonment, the abandonment plans must be submitted for approval.

Figure 1 shows a diagramatic sketch of the required casing program for industrial waste disposal wells. This diagram shows that the surface casing is required to be set through and below the fresh water sands and cemented to the surface. The injection, or long, string is required to be set to and through the injection sand and cemented to the surface. The effluent is then pumped through tubing which is set on a packer. The packer is set below the minimum depth allowed for waste disposal. This construction with three (3) strings of pipe and two (2) columns of cement between the fresh water sands and the waste material gives adequate protection to the fresh water sands.

Maryland[2]

The Department of Water Resources, a member agency of the Department of Natural Resources, has regulatory responsibility over industrial discharges. The Department operates under Article 96A, Annotated Code of Maryland. There are no specific laws presently on the books regulating subsurface disposal of industrial wastes.

Michigan[1,2,4,5]

The principal agency regulating the injection of industrial waste into subsurface stratum in Michigan is the Water Resources Commission. The initial law setting up the responsibilities of the agency is Act 245 of the Public Acts of 1929 as amended. The intent of Act 245 is to insure that "reasonable use" is made of the state's waters. The reasonable use doctrine is not violated if the waste stored in a particular geological stratum will not create a hazard to the safety, health or welfare of people or resources. The disposal program must reasonably insure that wastes will be confined in the stratum officially approved as the disposal reservoir.

Additional legislation known as the Mineral Well Act was passed in 1969 which has a direct bearing on waste disposal wells. The act supplementing the Water Resources Act, delegates the responsibility for regulating these wells on the "Supervisor of Wells" which is the State Geologist.

Pertinent Parts of Act 245 of the Public Acts of 1929 -

Act 245: "An act to create a water resources commission to protect and conserve the water resources of the state, to have control over the pollution of any waters of the state and the great lakes, with power to make rules and regulations governing the same, and to prescribe the powers and duties of such commission; to prohibit the pollution of any waters of the state and the great lakes; to designate the commission as the state agency to cooperate and negotiate with other governments and agencies in matters concerning the water resources of the state; and to provide penalties for the violation of this act.

"Sec. 2. The commission shall organize and make its own rules and regulations and procedure and shall meet at least once each month and shall keep a record of its proceedings. The commission shall protect and conserve the water resources of the state and shall have control of the pollution of surface or underground waters of the state of Michigan and the great lakes, which are or may be affected by waste disposal of municipalities, industries, public or private corporations, individuals, partnership associations, or any other entity. The commission is empowered to make or cause to be made surveys, studies and investigations of the uses of waters of the state, both surface and underground, and to cooperate with other governments, governmental units and agencies thereof in making such surveys, studies and investigations,

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"Sec. 6. (A). It shall be unlawful for any person directly or indirectly to discharge into the waters of the state any substance which is or may become injurious to the public health, safety, or welfare: or which is or may become injurious to domestic, commercial, industrial, agricultural, recreational, or other uses which are being made of such waters: or which is or may become injurious to the value or utility of riparian lands: or which is or may become injurious to livestock, wild animals, birds, fish, aquatic life, or plants or the growth or propagation thereof be prevented or injuriously affected: or whereby the value of fish and game is or may be destroyed or impaired.

"Sec. 8 (A). Whenever any person shall feel himself aggrieved by the restriction of polluting content or waste, or pollution, or any other order of the commission, he shall have a right to file a sworn petition with the commission, setting forth the grounds and reasons for his complaint and asking for a hearing of the matter involved. The commission shall thereupon fix the time and place for such hearing and shall notify the petitioner thereof. At such hearing the petitioner and any other interested party may appear, present witnesses and submit evidence. Following such hearing, the final order of determination of the commission upon such matter shall be conclusive unless reviewed in accordance with the provisions of the administrative procedures of Act No. 197 of the Public Acts of 1952, as amended, being Sections 24.101 to 24.110 of the compiled laws of 1948, or any amendment thereto, in the circuit court for the county of Ingham, or for the county in which such person resides, or for the county in which the alleged violation occurred.

"Sec. 11. Whenever the word "person" is used in this Act, it shall be construed to include any municipality, industry, public or private corporation, co-partnership, firm or any other entity whatsoever. Wherever the words "waters of the state" shall be used in this Act, they shall be construed to include lakes, rivers and streams and all other water courses and waters within the confines of the state and also the great lakes bordering thereon."

The Health Department under Act 294, P. A. 1965, known as the Water Quality Control Act, has some responsibility relative to subsurface disposal wells.

325.221 Sec. 1, Part (C) defines "well" as an opening in the surface of the earth for purposes of removing fresh water or a test well, recharge well or waste disposal well.

> "R 325.1671. Re-use of water and disposal wells.
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> Rule 171. (1) Water used for cooling parts of engines, air compressors or other equipment, or water used for air conditioning shall not be returned to any part of the potable water system.

> "(2) A well used for the disposal of waste water is regulated by Act 245 of the Public Acts of 1929, as amended, being Sections 323.1 to 323.12a of the Compiled Laws of 1948. An order of determination for such a well shall be obtained from the water resources commission. A well shall not be used for disposal of surface water, near surface water or ground water without first obtaining approval in writing from the director or his authorized agent. The director or his authorized agent has the right to refuse any such request, or prescribe methods of treatment prior to disposal."

When an industry requests permission to initiate a waste disposal program they must first fill out a "New Use Statement" application from the Water Resources Commission. This statement, along with supporting evidence, is reviewed by the Commission staff and Geological Survey personnel, and the Health Department. If the program is acceptable, it will go before the Commission, which meets every month. The decision made by the Commission will result in an "Order of Determination" approving or disapproving the "New Use Statement".

Act No. 315 of the Public Acts of 1969, the Mineral Well Act -

STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES
SUPERVISOR OF MINERAL WELLS

ACT NO. 315 OF THE PUBLIC ACTS OF 1969

An Act to provide control of the drilling, operating and abandoning of mineral wells to prevent surface and underground waste; to provide for a supervisor of mineral wells and prescribe his powers and duties; to provide for an advisory board and prescribe its duties; to provide for inspecting, repairing and plugging of mineral wells and for entering on private property for that purpose; to provide for the assessing of certain fees; to provide for the promulgation of rules and orders to enforce this act; and to prescribe penalties.

The People of the State of Michigan enact:

Sec. 1. This act shall be known and may be cited as the "Mineral Well Act".

Sec. 2. As used in this act:

(a) "Person" means any individual, corporation, company, association, joint venture, partnership, receiver, trustee, guardian, executor, administrator, personal representative or private organization of any kind.

(b) "Owner" means the person who has the right to drill, convert or operate any well subject to this act.

(c) "Operator" means the person, whether owner or not, supervising or responsible for drilling, operating, repairing, abandoning or plugging of wells subject to this act.

(d) "Supervisor" means the supervisor of mineral wells.

(e) "Board" means the advisory board appointed by the supervisor and approved by the director and commission.

(f) "Director" means the director of natural resources.

(g) "Commission" means the commission of natural resources.

(h) "Natural brine" means naturally occurring mineralized water other than potable or fresh water.

(i) "Artificial brine" means mineralized water formed by dissolving rock salt or other readily soluble rocks or minerals.

(j) "Underground storage cavity" means a cavity formed by dissolving rock salt or other readily soluble rock or mineral, by nuclear explosion, or by any other method for the purpose of storage or disposal.

(k) "Pollution" means damage or injury from the loss, escape or unapproved disposal of any substance at any well subject to this act.

(l) "Waste product" means waste or byproduct resulting from municipal or industrial operations or waste from any trade, manufacture, business or private pursuit which could cause pollution and for which underground disposal may be feasible or practical.

(m) "Mineral well" means any well subject to the provisions of this act.

(n) "Brine well" means a well drilled or converted for the purpose of producing natural or artifical brine.

(o) "Test well" means a well, core hole, core test, observation well or other well drilled from the surface to determine the presence of a mineral, mineral resource, ore, or rock unit, or to obtain geological or geophysical information or other subsurface data, but shall not include holes drilled in the operation of a quarry, open pit or underground mine.

(p) "Storage well" means a well drilled into a subsurface formation to develop an underground storage cavity for subsequent use in storage operations.

(q) "Disposal well" means a well drilled or converted for subsurface disposal of waste products or processed brine and its related surface facilities.

(r) "Exploratory purposes" means test well drilling for the specific purposes of discovering or outlining an ore body or mineable mineral resource.

(s) "Underground waste" means damage or injury to potable water, mineralized water, or other subsurface resources.

(t) "Surface waste" means damage to, injury to, or destruction of surface waters, soils, animal, fish and aquatic life or surface property from unnecessary seepage or loss incidental to or resulting from drilling, equipping, or operating a well or wells subject to this act.

Sec. 3. A person shall not cause surface or underground waste in the drilling, development, production, operation or plugging of wells subject to this act.

Sec. 4. The state geologist shall serve as the supervisor of mineral wells. He shall appoint, with the approval of the director, such assistants as necessary to carry out the provision of this act. The supervisor and assistants, in addition to salaries, shall receive reasonable traveling expenses while on business connected with their duties in accordance with standard travel regulations of the department of administration.

Sec. 5. The supervisor, after conferring with and receiving recommendations from owners and operators subject to this act, shall appoint 7 persons, subject to the approval of the director and commission, who shall constitute a board known as the mineral well advisory board which shall be representative of the industries subject to this act. The members of the board shall be chosen from owners and operators, or their managing agents or representatives, having ownership, production or operations which are subject to the provisions of this act. There shall be only 1 representative of 1 company or its subsidiaries or affiliates.

Sec. 6. The term of each member shall be 3 years. Of the first appointed board, 2 members shall serve for 1 year; 2 for 2 years; and 3 for 3 years. The supervisor, after conference with and receiving recommendations by owners and operators subject to this act, shall fill any vacancy in the membership subject to approval by the director and the commission. The supervisor may remove any member for good cause, after public hearing and approval by the commission. Each member of the board, unless removed as provided, shall serve until the appointment and qualification of his successor.

Sec. 7. The board, after approval by the commission, shall immediately and annually thereafter meet with the supervisor and organize by electing a chairman and vice-chairman. Four members of the board constitute a quorum for the transaction of business. A member of the staff of the supervisor shall be appointed by the board to serve as its secretary.

Sec. 8. The board shall meet semi-annually and hold such other meetings as it and the supervisor may deem necessary. Meetings shall be held at the office of the supervisor or at other designated places in the state as may be fixed by the board and the supervisor. Meetings may be called by the chairman, or in his absence by the vice-chairman, by a majority of the members or by the supervisor.

Sec. 9. The board may consult with the supervisor or commission and perform such other duties as may be designated to it. The board shall participate in all public hearings provided by this act, shall meet promptly thereafter with the supervisor and shall advise and make recommendations with respect to any rules or orders which may be considered for adoption pursuant to the evidence and testimony submitted.

Sec. 10. The supervisor shall keep the board informed of his activities by minutes of meetings and other agreed means.

Sec. 11. The members of the board shall receive no compensation but shall be reimbursed for expenses in connection with their duties in accordance with the standard travel regulations of the department of administration.

Sec. 12. (1) The commission shall act as an appeal board. Whenever the advisory board or any owner or operator deems any rule or order made by the supervisor to be unduly burdensome, inequitable or unwarranted, the board, owner or operator may appeal to the appeal board for relief, giving notice to the supervisor. The chairman of the commission shall set a date and place to hear such appeal, which may be at any regular meeting or at any special meeting of the commission duly called for that purpose. The supervisor, members of the board, or any person interested in the matter shall have the right to be heard at such hearing.

(2) The action of the appeal board shall be final with respect to an appeal by the advisory board, but any person may seek relief in the courts and the filing of an appeal as provided in this section shall not be a prerequisite to seeking relief in the courts.

Sec. 13. The supervisor shall have jurisdiction over the administration and enforcement of this act.

Sec. 14. The supervisor shall prevent the wastes defined in and prohibited by this act. Acting directly or through his deputy or authorized representative, and with the advice and recommendations of the board following public hearing, the supervisor shall promulgate rules subject to the approval of the commission and issue orders and instructions necessary to enforce these rules. Rules shall be adopted in accordance with the provisions of Act, No. 88 of the Public Acts of 1943, as amended, being Sections 24.71 to 24.80 of the Compiled Laws of 1948, and subject to Act, No. 197 of the Public Acts of 1952, as amended, being Sections 24.101 to 24.110 of the Compiled Laws of 1948.

Sec. 15. The supervisor, acting directly or through his deputy or authorized representative, may promulgate emergency orders without a public hearing to carry out the provisions of this act. Such emergency orders shall remain in force and effect not more than 21 days.

Sec. 16. The supervisor, acting directly or through his deputy or authorized representative, is specifically empowered to:

(a) Make inspections and provide for the keeping of records and checking on the accuracy thereof.

(b) Require the locating, drilling, deepening, reworking, reopening, casing, sealing, injecting, mechanical and chemical treating and plugging of wells subject to this act to be accomplished in a manner which is designed to prevent surface and underground waste.

(c) Designate after public hearing, and with the advice and recommendations of the board, those areas of the state in which there is no known or potential danger of surface or underground waste from test well drilling and in which permits to drill test wells will not be required.

(d) Require on all wells the keeping and filing of logs containing data which are appropriate to the purposes of this act. Logs on brine and test wells shall be held confidential for 10 years after completion and shall not be open to public inspection during that time except by written consent of the owner or operator. Logs for test wells drilled for exploratory purposes shall be held confidential until released by the owner or operator. The logs shall be opened to public inspection when the owner is no longer an active mineral producer, mineral lease holder, or owner of mineral lands in the state of Michigan.

(e) Require on storage and waste disposal wells, when specified by the supervisor, the keeping and filing of drillers' logs and sample logs, the running and filing of electrical and radioactivity logs, the keeping and filing of drill cuttings, cores, water samples, pilot injection test records, operating records and other reports.

(f) Release to the board or commission, for meetings and hearings, only data described in this section which are necessary to the administration of this act in the prevention or correction of surface or underground waste.

(g) Order through written notice the immediate suspension or prompt correction of any operation, condition or practice found to exist which is causing or resulting, or threatening to cause or result, in surface or underground waste.

(h) Require the filing of an adequate surety or security bond and provide for the release thereof.

(i) Qualify persons for blanket permits.

Sec. 17. (1) A person shall not drill, or begin the drilling, of any brine, storage or waste disposal well, or convert any well for these uses, until the owner directly or through his authorized representative files a written application for a permit to drill or convert a well, files a survey of the well site, files an approved surety and security bond, and receives a permit in accordance with the rules of the supervisor. A fee of $50.00 shall be charged for a brine, storage or waste disposal well permit. Within 10 days after receiving the prescribed application and fee, and following investigation, inspection and approval, the supervisor shall issue the well permit. No permit shall be issued to any owner or his authorized representative who does not comply with the rules of the supervisor or who is in violation of this act or any rule of the supervisor. Upon completion of the drilling or converting of a well for storage or waste disposal and after necessary testing by the owner to determine that the well can be used for these purposes and in a manner that will not cause surface or underground waste, the supervisor, upon receipt of appropriate evidence, shall approve and regulate the use of the well for storage or waste disposal. These operations shall be in accordance with the provisions of Act No. 245 of the Public Acts of 1929, as amended, being Sections 323.1 to 323.12a of the Compiled Laws of 1948. The supervisor may schedule a public hearing to consider the need or advisability of permitting the drilling or operating of a storage or waste disposal well, or converting a well for these uses, if the public safety or other interests are involved.

(2) A person shall not drill a test well, except as provided in subdivision (c) of Section 16, until the owner directly or through his authorized representative files a written application for a permit to drill, files an approved surety or security bond, and receives a permit in accordance with the rules of the supervisor. A fee of $1.00 shall be charged for a permit to drill a test well. Within 10 days after receiving the prescribed application and fee, and following necessary investigation, inspection and approval, the supervisor shall issue the permit. No permit shall be issued

to any owner or his authorized representative who does not comply with the rules of the supervisor or who is in violation of this act or any rule of the supervisor.

(3) No permit shall be required to drill a test well in those areas of the state where rocks of Precambrian age directly underlie unconsolidated surface deposits or in those areas which have been designated in accordance with the provisions of subdivision (c) of Section 16. However, within 2 years after completion of the drilling of the well, the owner shall advise the supervisor of the location of the well and file with the supervisor the log required under subdivision (d) of Section 16. The provisions of this act pertaining to the prevention and correction of surface and underground waste shall have the same application to these test wells as to other wells defined herein.

(4) Upon request, the supervisor may issue a blanket permit to drill test wells within a limited or local area where a geological test program is intended, and issue a blanket permit to drill test wells to qualified persons.

(5) All information and records pertaining to the application for and issuance of permits for wells and subject to this act shall be held confidential in the same manner as provided for logs and reports on these wells.

(6) The supervisor shall deposit all fees in the state treasury to be credited to the general fund.

Sec. 18. The supervisor may bring proceedings at law or in equity for the enforcement of this act and rules promulgated thereunder in the circuit court of Ingham County or in the circuit court of the county in which a violation shall have occurred. The attorney general shall represent the supervisor in all actions brought under this act.

Sec. 19. The circuit court of Ingham County shall have exclusive jurisdiction of all suits brought against the supervisor, board or commission, or any agent or employee thereof, by or on account of any matter or thing arising under the provisions of this act.

Sec. 20. (1) Jurisdictional requirements of notice of time, place and issues involved in all hearings required by this act shall be satisfied by publication once each week for 2 weeks consecutively in a newspaper of general circulation in the area where a specific matter of concern is located, if the last date of publication is at least 3 days prior to the date set for hearing.

(2) If a listing of interested persons is a part of the petition for hearing, or if the names of these persons are on record with the supervisor, service in the form of notice by certified or registered mail shall be made by the petitioner.

(3) The publishing of notices of hearings and payment for the publishing, shall be the responsibility of the petitioner. The supervisor shall be responsible for the publishing, and payment for the same, on all hearings initiated by him.

Sec. 21. All hearings and other actions pertaining to these hearings or investigations may be conducted by the supervisor, his deputy or authorized representative, and all acts of his deputy or authorized representative shall have the same force and effect as if done by the supervisor.

Sec. 22. (1) The supervisor may summon witnesses, administer oaths and, when necessary to carry out the provisions of this act, may require the production of appropriate records, books and documents.

(2) Upon failure or refusal of any person to comply with a subpoena issued by the supervisor, or upon the refusal of any witness to testify as to

any matter on which he may be interrogated as being pertinent to the hearing or investigation, the person or witness may be subject to a court order compelling him to comply with such subpoena, and to appear before the supervisor and produce such records, books and documents for examination and to give his testimony. The court shall have the power to punish for contempt or for refusal to testify.

Sec. 23. Whenever the supervisor, his deputy or his authorized representative has determined that an owner or operator has failed or neglected to case, seal, operate, repair or plug a well in accordance with the provisions of this act or the rules or orders adopted hereunder, notice of the determination shall be given to the owner or operator and to the surety executing the bond filed by such owner or operator. If the owner or operator, or surety, fails to correct the specified conditions in accordance with the rule or order of the supervisor within 60 days after service of notice, the supervisor may enter into or upon any private or public property on which the well is located, and across any private or public property to reach the well, and repair or correct the specified condition, and the owner, operator and surety shall be jointly and severally liable for all expenses incurred. The supervisor shall certify to the owner, operator and surety the claim of the state, listing therein the items of expense in making the repair or correction. The claims shall be paid by the owner or operator, or surety, within 30 days, and if not paid within that time the supervisor may bring suit in the circuit court of Ingham County against the owner, operator and surety, jointly and severally, for the collection.

Sec. 24. It is unlawful for any person:

(a) To wilfully violate any provision of this act or any rule or order of the supervisor.

(b) To drill or convert any well subject to this act without first obtaining a permit or to operate a storage or waste disposal well without approval as provided herein.

(c) To do any of the following for the purpose of evading or violating this act or any rule or order adopted hereunder:

(i) Make false entry or statement in any required report or record.

(ii) Omit or cause to be omitted from any required report or record full, true and correct entries as required by this act.

(iii) Remove from this state or destroy, mutilate, alter or falsify any required report or record.

Sec. 25. Any person in violation of this act shall be subject to a fine of not more than $1,000.00 and each day that the violation shall continue shall constitute a separate offense. The penalty shall be recovered by suit brought by the supervisor. Any person aiding or abetting in the violation of this act or any rule or order promulgated hereunder shall be subject to the same penalties as prescribed herein.

Sec. 26. The provisions of this act shall not apply to wells drilled under the authority of Act No. 61 of the Public Acts of 1939, as amended, being sections 319.1 to 319.27 of the Compiled Laws of 1948; Act. No. 325 of the Public Acts of 1937, as amended, being sections 319.51 to 319.82 of the Compiled Laws of 1948; Act No. 294 of the Public Acts of 1965, being sections 325.221 to 325.240 of the Compiled Laws of 1948; or Act No. 98 of the Public Acts of 1913, as amended, being sections 325.201 to 325.214 of the Compiled Laws of 1948. This act shall not be construed to supersede or contravene any of the provisions of Act No. 245 of the Public Acts of 1929, as amended.

PART 1. GENERAL PROVISIONS

R 299.2201. Applicability and effect on other laws.

Rule 1. (1) These rules implement the act and apply to mineral well operations except for special orders and determinations which may be adopted from time to time by the supervisor to apply to specifically designated areas or conditions in the state.

(2) A rule, special order or determination which may be adopted pursuant to the act shall not supersede or contravene any of the provisions of Act No. 61 of the Public Acts of 1939, as amended, being sections 319.1 to 319.27 of the Compiled Laws of 1948 (oil and gas act); Act No. 326 of the Public Acts of 1937, as amended, being sections 319.51 to 319.82 of the Compiled Laws of 1948 (natural gas act); Act No. 294 of the Public Acts of 1965, being sections 325.221 to 325.240 of the Compiled Laws of 1948 (groundwater quality control act); Act No. 98 of the Public Acts of 1913, as amended, being sections 325.201 to 325.214 of the Compiled Laws of 1948 (waterworks systems and sewage disposal systems act); or Act 245 of the Public Acts of 1929, as amended, being sections 323.1 to 323.12a of the Compiled Laws of 1948 (water resources commission act).

R 299.2205. Definitions A to G.

Rule 5. (1) Terms used in these rules which are defined in the act have the same meaning as given in the act.

(2) "Act" means Act No. 315 of the Public Acts of 1969, being sections 319.211 to 319.236 of the Compiled Laws of 1948.

(3) "Cement" means an approved type of sealing material.

(4) "Foundation boring" means a test well drilled for the purpose of determining the characteristics of the overburden or rock on which a foundation or structure will rest.

(5) "Geophysical testing hole" means a hole drilled for the purpose of providing a means for determining the physical or chemical characteristics of the earth.

R 299.2207. Definitions L to S.

Rule 7. (1) "Lost mineral well" means a well which cannot be completed because of mechanical difficulties, accidents of construction or geological conditions.

(2) "Mineral well" includes brine, storage, disposal and test wells.

(3) "Precambrian" means rocks older than the Jacobsville Sandstone.

(4) "Repair" or "maintenance" means changes to the retrievable components of a well, such as tubing, pumps, movable liners or minor reconditioning operations, such as backflushing or swabbing.

(5) "Reservoir" means a natural or artifically developed underground container of liquids or gas.

(6) "Rework" means to make changes or alterations in the permanent subsurface well equipment or in the original relationship between the permanent, non-retrievable equipment and the adjacent geologic formations, including but not limited to, squeezing with cement, repairing of casing leaks, cementing of casing or liners, casing or liner, perforations, well stimulation, deepening or plugging back operations.

(7) "Static water level" means the level at which water stands in a well when no water is being taken from the aquifer and is expressed as the distance from the ground surface.

PART 2. PERMITS

R 299.2211. Permits to drill, deepen, rework or convert mineral wells.

Rule 11. (1) An application for permit shall be filed and a permit received before commencing to drill a mineral well, to convert a mineral well to new use, to convert a well drilled under another act to a mineral well, or to deepen, rework or convert to new use a well drilled before the effective date of the act except as provided in Rule 27.

(2) The permit shall be posted in a conspicuous place at the well location and remain posted until the drilling of the well has been completed.

(3) The blanket permit to drill mineral wells, or a copy thereof, shall be posted in a conspicuous place at the well location or be in the possession of the driller.

R 299.2212. Permits to drill, deepen, rework or convert brine, storage and disposal wells; conditions for issuance.

Rule 12. Except as provided in Rule 29, and unless a public hearing on issuance of a permit is required under Rule 15, a permit to drill a brine, storage or disposal well, to convert a mineral well or to convert a well drilled before the effective date of the act or under another act to a brine, storage or disposal well, or to deepen or rework a brine, storage or disposal well drilled before the effective date of the act shall be issued within 10 days after receipt of application if:

(a) The exact location is established by a surveyor, engineer or competent company personnel and a stake or marker is set at the well location.

(b) A map or plat of the well area or company property is prepared indicating distances and directions from the well site to specific features, including lakes, streams, swamps, drainageways, wells including depth or deepest zone or formation, buildings, streets, highways, pipelines, power or other utility lines, railroads, and other features which lie within 300 feet, but shall not include proprietary information relating to manufacturing processes or unreasonable detail in manufacturing plant complexes.

(c) An accurately completed application is filed on prescribed forms with the map or plat and permit fee. The application shall be typewritten and contain a detailed account of the proposed well construction, drilling program and general operating plans and procedures. Supplemental information required by the application or by the supervisor shall be submitted on separate sheets with the application. Evidence of authority of a representative of the applicant shall be furnished on request of the supervisor. Inaccurate or incomplete maps, plats or application shall be corrected or completed and resubmitted.

(d) An organization report is filed on a prescribed form if requested by the supervisor.

(e) A surety or security bond is filed as required by these rules.

R 299.2213. Special requirements for permits.

Rule 13. (1) Special conditions or circumstances related to purpose, construction or location of a proposed mineral well may require investigation, review and determination by the supervisor or proofs of feasibility by the applicant, or both, before a permit may be issued.

(2) A person who intends to drill a storage or disposal well may be required to furnish advance notice of intent to drill, either published, or by certified mail, or both, to property owners within a 2-mile radius of the proposed well, or within such adjacent area as required by the supervisor.

(3) A person applying for a permit to drill a storage or disposal well shall file with the application a statement setting forth the bacterial, physical, chemical and other known characteristics of the wastes or materials to be stored or disposed.

R 299.2215. Public hearings on storage and disposal wells.

Rule 15. A public hearing to determine the need or advisability of issuance of a permit for drilling a storage or disposal well or converting a well to these uses may be held by the supervisor if he believes that the public safety or other interests are involved or receives from an owner, operator, lessee, lessor, the advisory board, or other person directly concerned with the matter proposed for hearing, a written request or petition which alleges that the public safety or other interest is involved.

R 299.2216. Confirmation of use of storage and disposal wells.

Rule 16. (1) Confirmation of the use of a storage or disposal well, the drilling of which has been authorized by a permit, is conditioned on approval of the well by an order of the water resources commission after completion and testing. If it is determined by inspection, and appropriate evidence is filed after testing, that a well can be used for storage or disposal in a manner that will not cause surface or underground waste, the supervisor shall approve and thereafter regulate the use and operation of the well in accordance with these rules and the order of the water resources commission.

(2) Requirements for testing are prescribed in rules 61 and 62. If a well is determined after testing to be unsuitable for storage or disposal use, it shall be abandoned and plugged as provided in part 7 or converted for another use as provided in rule 46.

R 299.2221. Individual test well permits.

Rule 21. Except as provided in rule 29, a permit to drill an individual test well shall be issued within 10 days after receipt of an application if:

(a) The exact location is established and a stake or marker is set at the well location.

(b) A plat or map is made of the well area or company property indicating the relationship of the well to lakes, streams, swamps, drainageways, wells buildings, streets, highways, pipelines, power and other utility lines, railroads and other features within 300 feet.

(c) An accurately completed application is filed on prescribed forms with the map or plat and fee. The application shall be typewritten and contain a detailed account of the proposed well construction, drilling procedure and plugging method.

(d) An organization report is filed on a prescribed form if requested by the supervisor.

(e) A surety or security bond is filed as required by these rules.

R 299.2222. Blanket test well permits.

Rule 22. A blanket permit may be issued to drill not more than 200 test wells, other than foundation borings or geophysical testing holes, within a limited or local area not exceeding 9 square miles if a geological test program is intended. A blanket permit is valid for not more than 1 year and expires on December 31. Test wells may be drilled in accordance with this rule if:

(a) An accurately completed application is filed on prescribed forms. The application shall be typewritten and contain a detailed account of the proposed well construction, drilling procedure and plugging method.

(b) Information is furnished in an accompanying letter and map indicating the purpose of the drilling project and the approximate number, location and depth of the wells.

(c) A permit fee is filed with the application.

(d) An organization report is filed on a prescribed form if requested by the supervisor.

(e) A surety or security bond is filed as provided by these rules.

R 299.2223. Geophysical testing holes.

Rule 23. (1) A blanket permit may be issued to drill geophysical testing holes within a specified area or for a specified investigative program. A blanket permit will not be issued for an area larger than 1 county and may be restricted to a smaller area by the supervisor for geologic reasons. A person may obtain separate blanket permits for more than 1 county or may obtain more than 1 blanket permit for the same county. A blanket permit is valid for not more than 1 year and expires on January 31. Not more than 200 holes may be drilled under a blanket permit except as authorized by the supervisor.

(2) Geophysical testing holes may be drilled in accordance with this rule if:

(a) An accurately completed, typewritten applicacation is filed on prescribed forms. The application shall contain a detailed account of the proposed well construction methods, drilling procedures and plugging methods. The plan shall propose alternative methods of plugging to be used to cope with various soil and water conditions within the area covered by the permit and shall specify criteria which will be applied to determine the applicable method.

(b) Information is furnished in an accompanying letter and map indicating the purpose of the drilling project and estimated number, general location, drilling pattern and approximate depth of holes.

(c) A permit fee is filed with the application.

(d) An organization report is filed on a prescribed form if requested by the supervisor.

(e) A surety or security bond is filed as provided in these rules.

(3) Within 60 days after completion of a geophysical test hole project or termination of a permit, whichever is first, a location plan and logs of wells shall be submitted in accordance with part 6.

(4) Issuance of a blanket permit for a specified area or period of time shall not be construed as granting exclusive rights to operate therein, nor does the permit

preclude the necessity of permission, permits, easements or other granting of privileges by other persons or agencies.

R 299.2225. Foundation borings.

Rule 25. (1) A blanket permit may be issued to drill foundation test borings within a specified area or for a specified investigative program. A blanket permit will not be issued for an area larger than 1 county and may be restricted to a smaller area by the supervisor for geologic reasons. A person may obtain separate blanket permits for more than 1 county or may obtain more than 1 blanket permit for the same county. A blanket permit is valid for not more than 1 year and expires on February 28. Not more than 200 holes may be drilled under a blanket permit except as authorized by the supervisor.

(2) A blanket permit shall be issued to qualified persons for drilling of foundation test borings if:

(a) An accurately completed application is filed on prescribed forms.

(b) Acceptable plans are proposed for the drilling and plugging. Plugging shall conform to procedures adopted by the supervisor based on recommended practices of the American Society of Civil Engineers, Michigan section, and the Department of State Highways. The plan shall propose alternate plugging methods for various soil and water conditions within the area covered by the permit and the criteria which will be applied to determine the applicable method.

(c) A permit fee is filed with the application.

(d) An organization report is filed on a prescribed form if requested by the supervisor.

(e) A surety or security bond is filed as provided in these rules.

(3) Within 60 days after completion of a test boring, test boring program, or termination of the permit,

whichever is first, a location plan and log of each well shall be submitted as provided in part 6. The log shall indicate the actual drilling and plugging procedures used.

(4) Issuance of a blanket permit for a specified area or period of time shall not be construed as granting exclusive rights to operate therein, nor does the permit preclude the necessity of permission, permits, easements or other granting of privileges by other persons or agencies.

R 299.2227. Test well permits; when not required.

Rule 27. (1) A permit to drill test wells is not required in areas of the state where rocks of Precambrian age lie directly under unconsolidated surface deposits; or in areas designated by the supervisor as being areas where there is no known or potential danger of surface or underground waste from test well drilling; except that the drilling shall be subject to rule 28 and other applicable rules. However, within 2 years after completion of the drilling of a well, the owner shall advise the supervisor of the location of the well and file with him the log required by part 6.

(2) A petition with supporting evidence may be filed with the supervisor requesting a hearing to determine the need or advisability of designating an additional area or areas where permits to drill test wells are not required except that the drilling shall be subject to rule 28 or other applicable rules. A petition shall be filed and hearings shall be scheduled in accordance with rules 92 to 94.

(3) A permit is not required for a hole drilled in the operation of a quarry, open pit or underground mine if the hole location is less than 500 feet from the quarry, open pit or mine.

(4) A permit is not required for a test hole 25 feet or less in depth which does not encounter bedrock. However, plugging of such a well shall be in accordance with rules 23, 25, 83 and 85.

R 299.2228. Wells located in waters of the state.

Rule 28. A mineral well to be located in or over the bed or waters of a stream, inland lake, a Great Lake, a natural or artificial impoundment, or other body of water shall be subject to approval by the commission before issuance of a permit.

R 299.2229. Denial of permits.

Rule 29. (1) The supervisor is prohibited by the act from issuing a permit to a person who is not in compliance with the act, or the rules or the orders of the supervisor.

(2) The supervisor shall deny issuance of a permit for a mineral well if he has reason to believe that the locating, drilling, constructing, reworking or operating of the well cannot be accomplished in a manner designed to prevent surface or underground waste.

PART 3. BONDS

R 299.2231. Surety and security bonds.

Rule 31. (1) A person who obtains a permit to drill, converts to, or acquires a mineral well shall file a surety or security bond, the amount of which shall be commensurate with the number of wells and the type of project.

(2) The amount of a surety bond shall be as follows:

(a) Single test well -- $2,000.00.

(b) Blanket bond for 2 or more test wells - $5,000.00.

(c) Single brine well -- $5,000.00.

(d) Blanket bond for 2 or more brine wells -- $15,000.00.

(e) Single storage or disposal well -- $15,000.00.

(f) Blanket bond for 2 or more storage
or disposal wells or a combination
of 2 or more test, brine, storage
or disposal wells -- $25,000.00.

(3) A security bond in the amount equal to the required surety may be deposited or required in lieu of a surety bond. A security bond shall consist of cash or negotiable securities and shall be deposited with the Department of Treasury. The securities shall be registered in the name of the State Treasurer of the State of Michigan. The State Treasurer shall charge a fee sufficient to reimburse him for not less than actual and necessary expenses incurred in connection with the deposit.

R 299.2235. Liability on bonds.

Rule 35. (1) Liability on a surety or security bond is conditioned on compliance with the act and the rules and the orders of the supervisor and continues until either of the following occurs:

(a) One year after the well or wells have been abandoned and satisfactorily plugged as provided in part 7 and approved by the supervisor, and all logs, plugging records and other pertinent data required by the act or rules and orders of the supervisor are filed and approved.

(b) Ownership of the well or wells is assumed by another person and the permits are transferred as provided in rule 42.

(2) The supervisor shall advise the surety and the principal when liability on a bond is terminated. A security bond deposited with the State Treasurer shall be released only upon written direction of the supervisor.

(3) The supervisor shall look to the surety or the security bond for correction of unsatisfactory conditions not otherwise corrected, and all expenses shall be paid through the surety or security bond in case of default by the principal.

(4) The surety under a blanket bond may refuse to accept additional wells or permits by giving 10 days notice by registered mail to the supervisor and the owner or operator. The bond shall continue in full force and effect relative to the well or wells for which permits were granted or transferred before the effective date of the notice. This cancellation procedure does not apply to single surety bonds.

PART 4. DISPOSITION OF PERMITS AND WELLS

R 299.2241. Changes of location before drilling.

Rule 41. A permit to drill shall be returned to the supervisor for cancellation, together with a new application for permit to drill at a new location if the location for which a permit to drill has been issued is changed before commencement of drilling. A new fee is not required, but drilling may be commenced only after the new application is processed and the new permit issued.

R 299.2242. Changes of ownership of wells.

Rule 42. (1) If a person who obtains a permit to drill disposes of his interest in a mineral well to a new owner while the well is being drilled, or after the well is completed, a notice of change of ownership and a request for transfer of permit shall be submitted to the supervisor on prescribed forms.

(2) The request for transfer of ownership may be approved if it is signed by the owner of record and the acquiring owner, and if the required bond if filed by the acquiring owner.

(3) A permit may be transferred only to persons who are in compliance with the act and the rules and orders of the supervisor.

R 299.2244. Termination of permits.

Rule 44. A permit to drill, rework or deepen a well terminates and is void 6 months after the date of issuance if the well for which the permit was issued has not been commenced, drilled, reworked or deepened in accordance with the permit except as provided by rules 22 to 25. The supervisor may grant an extension of time for commencement after receiving a written request and finding that the request is reasonable.

R 299.2246. Conversion of wells for new uses.

Rule 46. (1) An existing well, a mineral well, or a well drilled under another act may be converted to a new use if a permit is obtained in accordance with rule 12.

(2) A mineral well may be converted to a use other than provided by the act if the conversion is acceptable to the receiving authority and the well construction is suitably altered in accord with specifications to be stated by the supervisor and the receiving authority.

R 299.2247. Change of Status of wells.

Rule 47. (1) A mineral well may be deepened below the depth at which originally completed, may be reworked, may be shut-in for a period of time not to exceed 1 year except as provided in rule 61, or its status may otherwise be changed by any operation except for conversion to new use if:

(a) An application for permission to change the status of the well has been filed with the supervisor on prescribed forms. The application shall contain a detailed account of the work to be accomplished. Supplemental information required by the application or the supervisor shall be submitted on separate sheets with the application.

(b) A surety or security bond is filed as provided by these rules.

(c) The application has been approved by the supervisor and a permit to change the status of the well has been issued.

(2) Within 30 days after completion of the change of status operation, a complete record of the work performed

shall be filed with the supervisor on prescribed forms in accordance with rules 71 and 72.

(3) Normal repair or maintenance of mineral wells shall not constitute a change in status.

R 299.2248. Lost mineral wells.

Rule 48. A mineral well which cannot be completed shall be plugged promptly in accordance with part 7 unless converted to other use as provided in rule 46.

R 299.2249. Disposal of unconfirmed wells.

Rule 49. A well which is not confirmed or approved for disposal use under rule 16 shall be:

(a) Abandoned and plugged in accordance with part 7 or

(b) Converted for other use as provided in rule 46.

PART 5. CONSTRUCTION AND OPERATION OF WELLS

R 299.2251. Preparation of well locations.

Rule 51. (1) A pit or pits of a size approved by the supervisor shall be provided in close proximity to the well for the purpose of collecting and containing drill cuttings and confining drilling muds and fluids.

(2) Dikes may be required to prevent the escape of fluids from the well site, and other safeguards may be required for the protection of cultural or other adjacent features.

(3) Steel tanks, cribs or other approved containers may be required in an area where pits are not feasible or adequate or if the cuttings and fluids are to be removed from the premises.

(4) Drilling shall not be commenced until the person has complied with the methods and means specified by the supervisor to prevent pollution.

(5) Provision for protection of life and property may be required in a congested area. Fencing, gates, warning signs, cooperation of police and fire departments, and other protective safeguards may be required.

R 299.2252. Prevention of waste and pollution.

Rule 52. (1) A person who drills or operates a mineral well shall use appropriate and approved methods to prevent waste and pollution during drilling, testing, production, storage and disposal operations. The supervisor may issue orders and instructions and adopt, recommend or recognize guidelines relating to drilling, spacing or operating to cope with known or expected surface or underground conditions.

(2) A well site shall be maintained in an orderly manner and kept free and clear of debris and unnecessary or abandoned equipment.

R 299.2253. Casing and sealing brine, storage and disposal wells.

Rule 53. A specific casing and sealing program shall be submitted with each application for a permit to drill a brine, storage or disposal well, which shall be appropriate to the drilling methods, expected geologic conditions, and the intended ultimate use of the well, including, but not limited to, the following:

(a) Drive pipe shall be landed, or surface pipe set and cemented to the surface, at sufficient depth to protect fresh water aquifers.

(b) Intermediate casing or casings, if required, shall be run and cemented as approved by the supervisor. Centralizers may be required.

(c) The production or long string of casing shall be run and cemented as approved. Centralizers may be required.

(d) Tubing may be required for use in injection and withdrawal operations. The operator shall furnish to the supervisor evidence that the casing will not be exposed to undue corrosion. Installation of a packer on the tubing may be required.

(e) Hole diameters, casing weights and diameters and cementing procedures shall be subject to approval by the supervisor.

(f) The drilling fluid used with rotary drilling equipment shall be capable of preventing blowouts and flows and sealing off each oil, gas, brine or fresh water stratum above the producing horizon or objective formation.

(g) A well head shall be equipped with blowout preventer, master gate valve, or control head, and securely anchored flow lines, appropriate to the type of drilling method, and shall be kept in good working condition. Records of pressure and mechanical tests of well head equipment shall be entered in the log book, signed by the driller, and kept available for inspection by the supervisor or his representative.

R 299.2254. Casing and sealing test wells.

Rule 54. A combination of casing and sealing may be required on a test well to provide protection to the waters of the state and to prevent migration of fluids between layers of earth materials.

R 299.2255. Cavities and reservoirs for storage use.

Rule 55. (1) A cavity or reservoir may be created by solution, by fracturing, or by any chemical, physical or mechanical method, or any combination thereof.

(2) Disposal of the salt water or other mineralized water resulting from development of a cavity or reservoir shall be subject to Act No. 245 of the Public Acts of 1929, as amended, being Sections 323.1 to 323.13 of the Compiled Laws of 1948.

R 299.2256. Oil, gas, brine and fresh water.

Rule 56. (1) Oil, gas, brine and fresh water encountered shall be confined to the strata in which they occur by either of the following:

(a) Specified casing and sealing requirements.

(b) Plugging operations in accordance with part 7.

(2) An unusual, unexpected, or difficultly-controllable large volume of oil, gas, brine or flowing fresh water or a condition hazardous to public health, safety or waters of the state shall be reported immediately to the supervisor.

R 299.2257. Removal or stripping of casings.

Rule 57. Removal or stripping of a casing from a well during drilling or after completion is permitted only when approved by the supervisor.

R 299.2261. Initial testing of storage wells, cavities and reservoirs.

Rule 61. Data shall be reported to the supervisor demonstrating that a storage well, cavity or reservoir is suitable for the proposed use. These data shall be obtained by appropriate testing and measurement procedures, including the following:

(a) The casing, tubing and well head equipment shall be pressure tested at a minimum of 133 percent of the expected operating pressure.

(b) The cavity or reservoir shall be tested to demonstrate to the supervisor that there will be no leaks or losses of fluids into the adjacent formations at expected operating pressure.

(c) The size, shape and volume of the cavity or reservoir shall be determined as accurately as practicable.

R 299.2262. Initial testing of disposal wells.

Rule 62. (1) Tests, logs and direct measurements shall be conducted to determine to the satisfaction of the supervisor that the well and disposal formations are suitable for disposal or storage of wastes and that overlying and underlying rock units, zones, intervals, beds or formations are adequate to confine disposed or stored fluids. The tests shall include, but not be limited to, the following data:

(a) Physical, chemical and lithologic properties of formation materials and fluids.

(b) Formation porosity and permeability.

(c) Compatability of waste or stored fluids with naturally-occurring formation fluids and formation materials.

(d) Formation temperature and pressure.

(2) Tests, logs and direct measurements shall be conducted in accordance with procedures acceptable to the supervisor. Results shall be filed with the supervisor. Waste products or stored materials shall be injected and confined to the zone, interval, bed or formation designated for disposal or storage use. Compliance with the act and rules promulgated thereunder does not obviate the necessity of compliance with any order or other action of the Water Resources Commission in accordance with Act No. 245 of the Public Acts of 1929, as amended, or any other pertinent act.

R 299.2265. Periodic testing of brine wells.

Rule 65. Testing shall be accomplished not less than biennially on a brine well to determine and locate leaks or losses of fluids or pressure in tubing, casing, surface or drive pipe, and well head equipment. Results of the testing shall be reported to the supervisor. The supervisor may accept continuous monitoring data in lieu of some periodic testing.

R 299.2266. Operation of brine wells.

Rule 66. (1) The handling, piping and surface storage of brines shall be accomplished in a manner to prevent leaks and losses into surface or underground waters.

(2) The use of unlined surface pits or earthen reservoirs is prohibited.

(3) Records of volume of fluids withdrawn and injected shall be maintained on a monthly basis. These records shall be preserved by the operator and be subject to inspection and evaluation by the supervisor. The operator shall file an annual report with the supervisor showing:

(a) Volume relationship or withdrawal-injection ratios.

(b) A summary statement or tabulation of injection pressures and injection pressure variations.

(4) Any anomalous condition, including a rate or pressure variation, shall be reported promptly to the supervisor.

R 299.2267. Periodic testing of storage and disposal wells.

Rule 67. At least once during each calendar quarter a storage or disposal well shall be tested by the operator by the variable-rate input method, the pressure fall-off test, or any other performance test as the supervisor may require or approve. Sufficient data shall be collected during each calendar year to facilitate analysis of static and injection formation pressures, storage zone limits or boundaries, changes in formation characteristics, and other information commonly derivable from such tests. Data shall be preserved by the operator for inspection by the supervisor or his agent. At the end of each calendar year a summary and analysis of test data shall be supplied to the supervisor. The supervisor may accept continuous monitoring data in lieu of some periodic testing.

R 299.2268. Operation of storage and disposal wells.

Rule 68. (1) Anomalous behavior of a storage or disposal well shall be reported promptly to the supervisor. In case of an anomalous behavior arising from or likely to [illegible] from storage or disposal practices, the supervisor may order reduction or cessation of storage or disposal operations, may order additional testing by the operato[illegible] may order the drilling of an observation well by the operator to provide additional data on the movement and behavior of injected fluids, indigenous formation fluids or stored fluids.

(2) Elimination and correction of leaks or losses of fluids or pressure in wells, reservoirs and surface installations shall be made immediately.

(3) An operation which may cause or create a condition endangering public health or welfare shall be avoided.

(4) Adequate equipment and installations at a disposal well for appropriate testing and monitoring of the operation shall be used.

(5) Wastes shall be treated before injection unless otherwise approved by the supervisor.

(6) Records or reports, forms, charts of operating pressures, rates of injection, types and volumes of fluids injected or withdrawn, and other pertinent information shall be maintained and submitted monthly to the supervisor or at other specified times.

(7) Wastes shall be treated and stored before injection in a manner to avoid surface or ground water pollution.

(8) A request for change of status shall be filed before any rework operations are commenced.

(9) Volumes, injection rates and pressures used shall not exceed those specified in the approval of the disposal or storage use.

(10) Only wastes specified in the statement required by rule 13 may be injected into a well.

(11) Not less than 1 observation well, located within 100 feet of the disposal well, shall be provided for each well used for the disposal or storage of radioactive materials. An observation well shall penetrate, as a minimum, the formational unit immediately overlying and confining the disposal formation. The well or wells shall be used for continuous control and monitoring on a scale commensurate with the level of the radioactivity.

PART 6. RECORDS

R 299.2271. Kinds and filing.

Rule 71. (1) A person who drills a mineral well shall keep, preserve and file with the supervisor drilling logs, sample logs, and electric or radiation or other physical, chemical or mechanical logs as designated or approved by the supervisor. Logs shall consist of data accurately recorded during drilling, deepening, reworking and testing of wells or the subsequent analysis or description of earth materials removed. Logs shall be filed within 60 days after the completion of drilling, except test wells drilled in accordance with rules 22 to 27, on forms prescribed or approved by the supervisor.

(2) The permittee shall obtain and transmit to the supervisor the records and logs of work done on wells by contractual service companies that specialize in logging or cementing or other special well treatment procedures.

R 299.2272. Content.

Rule 72. A log of a mineral well shall include all normally recorded information for the particular type well being constructed and shall include, but not be limited to:

(a) For a test well, the owner's name, permit number, site location, elevation, drilling contractor, drilling method, casing record, description and thickness of geologic materials penetrated, static water levels, flowing water zones, total depth, beginning and completion dates, occurrences of oil, gas or salt water, and description of procedures and materials used in plugging.

(b) For a brine, storage or disposal well, the owner's name, permit number, site location, elevation, drilling contractor, drilling method, casing record, cementing record, description and thickness of geologic materials penetrated, total depth, static water levels, flowing water zones, occurrences of oil, gas or salt water, beginning and completion dates. data on perforating, acidizing, fracturing, shooting and testing, electrical, radiation or other types of mechanical, chemical or physical records; sample descriptions, core descriptions, data on well head completion, and data on subsurface equipment installed.

(c) For a reworked well, the owner's name, permit number, site location, contractor's name, reason for rework, changes made within the well and at the well head, and reports of testing accomplished.

§ 299.2273. Confidentiality.

Rule 73. Records shall be kept confidential as follows:

(a) A log of a brine or test well shall be kept confidential for 10 years after well completion, except as otherwise released by the owner.

(b) A log of an exploratory test well shall be kept confidential until released by the owner or operator.

(c) A log of a brine or test well for exploratory purposes shall be kept confidential until the owner is no longer an active producer, mineral lease holder, or owner of mineral lands in the state.

PART 7. PLUGGING

§ 299.2281. Plugging of mineral wells.

Rule 81. A mineral well shall be plugged promptly after abandonment or termination of the project in accordance with plugging procedures specified by the supervisor. A well which has been inactive for 1 year is considered to have been abandoned unless otherwise authorized by the supervisor.

R 299.2282. Plugging of brine, storage and disposal wells, cavities and reservoirs.

Rule 82. (1) The abandonment of a brine, storage or disposal well, a solution cavity, or a reservoir shall require the filing of a notice of intention to abandon on a prescribed form and plugging instructions shall be issued by the supervisor before plugging operations are commenced.

(2) The plugging instructions shall specify the type and amount of plugging material to be used, depths at which bridges may be set, depths and lengths of cement plugs, and other requirements for adequate plugging.

(3) Fluids and gases shall be confined to the strata in which they occur by use of mud-laden fluid, cement, other suitable material or combinations thereof. The amount, type and kind of material and the method of placement shall be prescribed or approved by the supervisor.

(4) The surface or drive pipe shall be abandoned with the hole except when otherwise approved by the supervisor.

(5) The surface or drive pipe shall be cut off below ground level, except as otherwise approved by the supervisor, and a cement plug, welded plate or other approved seal placed at the top of the pipe.

R 299.2283. Plugging of test wells.

Rule 83. (1) Plugging of a test well shall be accomplished in accordance with specifications made at the time of the application for a permit to drill. The plugging operation may require the use of mud-laden fluid, cement, other suitable material, or a combination of 2 or more of these items. Fluids and gases shall be sealed off and confined to the strata in which they occur. A suitable plug may be required at the surface.

(2) The plugging of a test well drilled without issuance of a permit shall be in the manner as a test well for which a permit was issued.

R 299.2285. Clean-up of abandoned well sites.

Rule 85. The well pit or cellar and all pits and excavations shall be filled and leveled off at the surface, debris shall be removed, and all conditions which may create a nuisance or a fire or pollution hazard shall be eliminated. The surface of the abandoned well site shall be returned as nearly as possible to its original condition.

R 299.2287. Plugging reports and records.

Rule 87. (1) A report shall be filed with the supervisor after plugging of a test well. This report may cover a number of wells drilled under a blanket permit.

(2) Well plugging records shall be filed on prescribed forms following the plugging of a brine, storage, disposal and single test well. This record shall indicate how the well was plugged, the casing recovered and abandoned with the hole, and the condition of the abandoned well site.

(3) The plugging record on a test well drilled without the issuance of a permit shall be attached to or made a part of the log when it is filed after the prescribed 2 years.

(4) Plugging records for a brine, storage or disposal well shall be filed within 30 days after completion of the plugging.

PART 8. ADMINISTRATION

R 299.2291. Forms.

Rule 91. Forms required by these rules are prescribed by the supervisor and will be available from his office.

R 299.2292. Public hearing requests and petitions.

Rule 92. (1) The supervisor, the board or any person affected by a mineral well matter may request or petition for a public hearing before the supervisor or the board to consider the need or advisability of an action or order by the supervisor. The purpose of the hearing will be to receive evidence, testimony, statements and exhibits pertaining to the matter to be heard.

(2) A petition or written request by any person other than the supervisor or board for a hearing shall be filed with the supervisor and shall include the following and other information which may be pertinent:

(a) Name and address of petitioner.

(b) Purpose for which the hearing is requested.

(c) Descriptions, sections, townships and counties involved in the matter to be heard.

(d) Maps, plats and exhibits which may be useful in considering the matter to be heard.

(e) Names and addresses of persons known to be concerned with the matter to be heard and who should be notified of the hearing.

(f) Name of the newspaper circulated in the area of the matter to be heard.

R 299.2293. Notice of public hearings.

Rule 93. The supervisor shall prepare notices of all public hearings. Notice of the time, place and issues involved shall be published once each week for 2 consecutive weeks in a newspaper circulated in the area where the matter of concern is located. The last date of publication shall be at least 3 days before the date set for hearing. The petitioner is responsible for the publishing of notices and payment for the publishing, except that the supervisor is responsible for the publishing and payment for the publishing on a hearing initiated by him.

R 299.2294. Service of notices.

Rule 94. A person whose name is listed in the petition, or otherwise known by the supervisor or the petitioner to be concerned, shall be furnished with a copy of the notice by certified or registered mail. The petitioner shall furnish these notices and submit return receipts and affidavits of publication to the supervisor before the date of the hearing.

R 299.2295. Determinations by supervisor.

Rule 95. The board shall participate in all hearings and shall meet privately with the supervisor following each hearing. It shall review the evidence and testimony submitted and make recommendations thereon to the supervisor. The supervisor, after evaluating the evidence and testimony and giving due consideration to the recommendations of the board, shall adopt the appropriate rule or order or make the determination which in his judgment is warranted on the matter.

R 299.2296. Emergency orders of supervisor.

Rule 96. An emergency order may be issued by the supervisor without public hearing and with immediate effect to apply to situations requiring prompt control of pollution or elimination of any other hazardous condition. An emergency order shall remain in effect not more than 21 days. It becomes void unless made permanent or replaced by a new order adopted following a public hearing which shall be promptly commenced.

R 299.2297. Extension of time for compliance.

Rule 97. The supervisor may grant an extension of time for compliance with these rules after receipt of a written request from an operator setting forth appropriate evidence acceptable to the supervisor.

R 299.2298. Enforcement by supervisor.

Rule 98. The supervisor by virtue of sections 14 and 16 of the act is empowered to enforce all rules, issue orders and instructions necessary to enforce these rules, order suspension or correction of any operation, condition or practice which is causing or resulting, or threatening to cause or result, in surface or underground waste, and do whatever is necessary to carry out the purpose and intent of the act and the rules, whether or not such orders or instructions are indicated, specified or enumerated in the act or in the rules.

Mississippi[3]

The Air and Water Pollution Control Commission, Box 827, Jackson, would apparently have jurisdiction over subsurface disposal. They are presently making a study of the various rules and regulations of other states with the intent of establishing some for Mississippi.

The State Board of Health's Regulation 52, 40-110 governs industrial waste disposal. The Oil and Gas Conservation Commission's role in this respect would be only to issue a permit to drill the well. There is no direct reference to subsurface disposal in the above regulation which appears to apply generally to surface waters. However, it does regulate industrial and municipal discharges into the state's waters which can be liberally interpreted to mean subsurface aquifers.

Missouri[12]

The Clean Water Commission of the Department of Public Health and Welfare has jurisdiction over all matters involving ground water. Any injection of industrial waste into the subsurface in Missouri is specifically prohibited in Chapter 564.025 of the Missouri Revised Statutes, Cumulative Supplement, 1973.

Montana[1,2]

The State Board of Health's regulation 52, 40-10 governs industrial waste disposal. The Oil and Gas Conservation Commission's role in this respect would be only to issue a permit to drill the well. There is no direct reference to subsurface disposal in the above regulation which appears to apply generally to surface waters. However, it does regulate industrial and municipal discharges into the State's waters which can be liberally interpreted to mean subsurface aquifers.

The Oil and Gas Conservation Commission (60127C) has the power to require the drilling, casing, and plugging of oil and gas wells so as to prevent pollution of fresh water supplies and also has the power to regulate disposal of salt water and other oil field wastes. It is quite likely that the Commission could actively participate in regulating or approving any subsurface disposal program.

Nebraska[1]

Nebraska has no specific laws regulating the subsurface disposal of industrial wastes other than oil and gas field brines. The agency principally responsible for water pollution control is the State Pollution Control Council which is a part of the State Department of Health (Revised Statutes of Nebraska, 71-3001, et. seq.). The Council sets quality standards and formulates broad general policy. The Department of Health is charged with the administration of the Water Pollution Act in accordance with the law and policies and regulations that are established by the Council. The Council itself holds hearings and adopts rules and regulations and orders regarding pollution and abatement thereof.

Although the Board may review and make recommendations of plans for disposal systems, the Council is the one that must actually approve the plans and issue the permits. The Oil and Gas Conservation Commission has the authority to regulate the disposal of salt water and other oil field wastes.

In all probability should subsurface disposal of wastes become a reality the above agencies under present laws would be directly involved. Other agencies which should be consulted are the State Department of Water Resources and the Geological Survey. The Department of Water Resources is represented on the Council. It is quite likely that this method of disposal will not be used until adequate protective legislation has been adopted.

New Mexico[1]

The Department of Health probably would have this authority, at least in the area of enforcement. Legislation aimed at air pollution and water pollution may have some bearing on subsurface disposal.

New York[2,11]

The present policies relative to deep well injection were adopted by the Department of Health, May 29, 1969. These are listed below:

A. The injection of liquid wastes by deep wells is considered a last resort after all other methods have been evaluated; it is a method for gaining long-term storage rather than treatment. The applicant must demonstrate that this method (1) is the optimal approach, and (2) has the least effect to the total environment.

B. Fresh ground waters and potential mineral resources which may be subject to future development must be protected against any adverse effect by the disposal of wastes into the subsurface.

C. It is incumbent upon the applicant to obtain a competent geologist and a professional engineer for the necessary studies, design and preparation of reports and plans. This should include, but not be limited to the environmental, economical and technical implications.

D. Continuous injection at critical input (Hydraulic parting) pressures is prohibited and will not be approved.

E. A permit must be issued prior to the construction and operation of any disposal of wastes through deep well injection.

F. Concurrence must be obtained from the Division of Oil and Gas of the Conservation Department and the office of the State Geologist of the Education Department.

North Dakota[1]

The Water Conservation Commission does have power for the complete supervision and control of acts tending to pollute water courses (N.D. C.C. § 61-02-14 (2) C). The act does not limit the authority of the Department of Health to prevent pollution, and the Commission shall not declare waters to be polluted without a finding to that effect by the Department of Health (§ 61-02-15). Also the State Industrial Commission has jurisdiction to prevent pollution by oil, gas, or salt water (N.D. C.C. § 38-08-04) with the State Geologist acting as the administrative agent. It is quite likely that the Industrial Commission would be involved in the subsurface disposal of industrial wastes should such a program or programs be instigated in North Dakota. The State Water Pollution Control Board, an agency established by the 1967 Legislature, would probably enter the picture as well as the above named agencies, all of which are represented on the Board.

Ohio[1,12]

In June of 1967 the Ohio Legislature enacted changes in their Oil and Gas Code which incorporated specific laws for industrial waste disposal wells. Jurisdiction would be under the Division of Oil and Gas. Although that Division can set up specific regulations and enforcement procedure, the multi-agency approach will still be used in approving any application for a disposal well. The other agencies involved are Water Pollution Control Board, Geological Survey, Division of Mines, and the Health Department.

Amended Senate Bill No. 226 -

To amend sections 1509.01 and 1509.06 and to enact sections 1509.051 and 1509.081 of the Revised Code relative to issuance of liquid disposal permits, and to declare an emergency.

SECTION 1. That sections 1509.01 and 1509.06 be amended and sections 1509.051 and 1509.081 of the Revised Code be enacted to read as follows:

Sec. 1509.01. As used in sections 1509.01 to 1509.99, inclusive, of the Revised Code:

(A) "Well" means any borehole, whether drilled or bored, within the state, for production, extraction, or injection of any gas or liquid mineral, excluding potable water to be used as such, but including natural or artificial brines and oil field waters, sewage, and any liquid used in or resulting from any process or industry, manufacture, trade, business, or agriculture.

(B) "Oil" means crude petroleum oil and all other hydrocarbons, regardless of gravity, that are produced in liquid form by ordinary production methods, but does not include hydrocarbons that were originally in a gaseous phase in the reservoir.

(C) "Gas" means all natural gas and all other fluid hydrocarbons not defined above as oil, including condensate.

(D) "Condensate" means liquid hydrocarbons that were originally in the gaseous phase in the reservoir.

(E) "Pool" means an underground reservoir containing a common accumulation of oil or gas, or both, but does not include a gas storage reservoir. Each zone of a geological structure that is completely separated from any other zone in the same structure may contain a separate pool.

(F) "Field" means the general area underlaid by one or more pools.

(G) "Drilling unit" means the minimum acreage on which one well may be drilled, but does not apply to a well for injecting gas into or removing gas from a gas storage reservoir.

(H) "Waste" includes:

(1) Physical waste as such term is generally understood in the oil and gas industry;

(2) Inefficient, excessive, or improper use, or the unnecessary dissipation of, reservoir energy.

(3) Inefficient storing of oil or gas;

(4) Locating, drilling, equipping, operating, or producing an oil or gas well in a manner that reduces or tends to reduce the quantity of oil or gas ultimately recoverable under prudent and proper operations from the pool into which it is drilled, or that causes or tends to cause unnecessary or excessive surface loss or destruction of oil or gas;

(5) Other underground or surface waste in the production or storage of oil, gas, or condensate, however caused.

(I) "Correlative rights" means the reasonable opportunity to every person entitled thereto to recover and receive the oil and gas in and under his tract or tracts, or the equivalent thereof, without having to drill unnecessary wells or incur other unnecessary expense.

(J) "Tract" means a single, individually taxed parcel of land appearing on the tax list.

(K) "Owner", unless referring to a mine, means the person who has the right to drill on a tract or drilling unit and to drill into and produce from a pool and to appropriate the oil or gas that he produced therefrom either for himself or for others.

(L) "Royalty interest" means the fee holder's interest in the production from a well, usually one-eight of the gross production.

(M) "Discovery well" means the first well capable of producing oil or gas in commercial quantities from a pool.

(N) "Prepared clay" means a clay which is plastic and is thoroughly saturated with fresh water to a weight and consistency great enough to settle through saltwater in the well in which it is to be used, except as otherwise approved by the chief of the division of oil and gas.

(O) "Rock sediment" means the combined cutting and residue from drilling sedimentary rocks and formation.

(P) "Excavations and workings", "mine", and "pillar" have the meaning set forth in section 4151.01 of the Revised Code.

(Q) "Coal bearing township" means a township designated as such by the chief of the division of mines under section 4151.11 of the Revised Code.

(R) "Gas storage reservoir" means a continuous area of a subterranean porous sand or rock stratum or strata into which gas is or may be injected for the purpose of storing it therein and removing it therefrom, and includes a gas storage reservoir as defined in division (A) of section 4161.01 of the Revised Code.

Sec. 1509.051. No person shall use a well for the injection of sewage or any liquid used in or resulting from any process of industry, manufacture, trade, business, or agriculture, without having a liquid disposal permit issued by the chief of the division of oil and gas, and the original permit or a true copy thereof displayed in a conspicuous and easily accessible place at the well site.

A permit to drill a new well, drill an existing well deeper, or to reopen a well, is a liquid disposal permit if the permit was issued in satisfaction of the requirements of section 1509.081 of the Revised Code, or if a permit authorizing such use has been issued under section 1509.21 of the Revised Code, or if such use is approved by the chief under section 1509.22 of the Revised Code.

Sec. 1509.06. An application for a permit to drill a new well, drill an existing well deeper, reopen a well, *** plug back a well to a different source of supply, or use a well for injection of a liquid for which a permit is required by section 1509.051 of the Revised Code, shall be filed with the chief of the division of oil and gas upon such form as the chief prescribes and shall contain the following information:

(A) The name and address of the owner;

(B) The signature of the owner or his authorized agent. When an authorized agent signs an application it shall be accompanied by a certified copy of his appointment as such agent.

(C) The names and addresses of all persons holding the royalty interest in the tract upon which the well is to be drilled or within a proposed drilling unit.

(D) The location of the tract or drilling unit on which the well is to be drilled identified by section or lot number, city village, township, and county;

(E) Designation of well by name and number;

(F) The geological formation to be tested or used and the proposed total depth of the well;

(G) The type of drilling equipment to be used;

(H) The name and address of the corporate surety and the identifying number of the bond;

(I) The plan for disposal of water and other waste substances resulting, obtained, or produced in connection with exploration, drilling, or production of oil or gas.

(J) If the well is for the *** injection of a liquid, identity of the geological formation to be used as the *** injection medium and the composition of the liquid to be injected.

Each such application shall be accompanied by a map, on a scale not smaller than four hundred feet to the inch, prepared by an Ohio registered surveyor, showing the location of such well and containing such other data as may be prescribed by the chief. If the well is or is to be located within the excavations and workings of a mine the map shall also include the location of such mine, the name of the mine, and the name of the person operating the mine.

Each application to drill or reopen a well, except a well drilled or reopened for purposes of section 1509.22 of the Revised Code, shall also be accompanied by a fee of thirty-five dollars for a well two thousand feet or more in depth or twenty dollars for a well less than two thousand feet in depth or for a well for injecting gas into or removing gas from an underground gas storage reservoir. If for any reason the permit is denied, such fee shall be returned to the applicant.

Sec. 1509.081. Upon receipt of an application for a permit to drill a new well, drill an existing well deeper, reopen a well, or use a well, for injection of a liquid for which a permit is required by section 1509.051 of the Revised Code, other than one which comes within the requirements of section 1509.21 or section 1509.22 of the Revised Code, the chief of the division of oil and gas shall determine whether the proposed injection would present an unreasonable risk that waste or contamination of oil or gas in the earth will occur. If he determines such risk to exist, he shall make an order rejecting the application. If he determines such risk not to exist, he shall transmit copies of the application and the map required by section 1509.06 of the Revised Code to the water pollution control board, the director of health, the chief of the division of geological survey, the chief of the division of water and, if so required by section 1509.08 of the Revised Code, to the chief of the division of mines.

The chief of the division of geological survey shall approve the application unless he determines that the proposed injection would present an unreasonable risk of loss or damage to valuable mineral resources.

The chief of the division of water shall make a report and recommendation to the director of natural resources.

The water pollution control board shall approve the application if it determines that the proposed injection will not cause pollution as defined in division (A) of section 6111.01 of the Revised Code.

Upon approval by the water pollution control board, the department of health under section 3701.19 of the Revised Code, and the chief of the division of geological survey and by the chief of the division of mines, if required by section 1509.08 of the Revised Code the chief of the division of oil and gas shall issue a liquid disposal permit with such conditions as may be necessary to protect health, safety, or the conservation of natural resources, including all conditions appended by the water pollution control board and the department of health.

If the chief is unable to obtain the required approvals, he shall issue an order denying the application. In an appeal from such an order where the application was denied because of lack of approval by an agency or agencies other than the division of oil and gas, the appeal shall be taken under section 119.12 of the Revised Code as if the order had been made by the agency whose approval is lacking.

The chief of the division of oil and gas may adopt rules and regulations for the administration and implementation of this section as may be necessary to protect health, safety, or the conservation of natural resources.

The chief may order that a liquid disposal permit be suspended and that operations cease if he determines that the well being operated in violation of law, regulation, order, or condition of the permit. Upon service of a copy of the order upon the permit holder, his agent, or assignee, the permit and operations thereunder shall be immediately suspended without prior hearing, and shall remain suspended until the violation is corrected and the order of suspension is lifted. If a violation is the second within a one-year period, the chief may, after hearing, revoke the permit.

The chief may order that a liquid disposal permit be suspended and that operations cease if he has reasonable cause to believe that the permit would not have been issued if information available at the time of suspension had been available at the time a determination was made by one of the agencies acting under authority of this section. Upon service of a copy of the order upon the permit holder, his agent, or assignee, the permit and operations thereunder shall be immediately suspended without prior hearing, but a permit may not be suspended for such reason without prior hearing unless immediate suspension is necessary to prevent waste or contamination of oil or gas, pollution as defined in division (A) of section 6111.01 of the Revised Code, damage to valuable mineral resources, or danger to human life or health. If after hearing the chief determines that the permit would not have been issued if the information available at the time of the hearing had been available at the time a determination was made by one of the agencies acting under authority of this section, he shall revoke the permit.

A revocation of permit shall not prejudice the right of the holder to obtain another permit. When a permit has been revoked, the permit holder or another person responsible therefor shall immediately plug the well.

In an appeal from an order of suspension or revocation where the order was made because of objection of an agency or agencies named in this section other than the division of oil or gas, the appeal shall be taken under section 119.12 of the Revised Code as if the order had been made by the agency upon whose objection the order was based.

SECTION 2. That existing sections 1509.01 and 1509.06 of the Revised Code are hereby repealed.

SECTION 3. This act is hereby declared to be an emergency measure necessary for the immediate preservation of the public peace, health, and safety. The reason for this necessity is that its enactment into law at the earliest possible time will enable industries which have a present need to dispose of untreatable waste materials to dispose of them safely underground, and thus avoid pollution of the rivers and streams of the state. Therefore this act shall go into immediate effect.

Oklahoma[13,15]

The Oklahoma Water Resources Board, created by an Act of the 26th Legislature, Title 82, Section 1071, O.S. 1961, approved May 2, 1957, is the controlling authority over deep-well injection of industrial waste. Exceptions would involve interested agencies which are charged with specific duties as applied to surface and ground waters. These agencies would be the Corporation Commission, Health Department, and the Wildlife Conservation Commission. Opinions are usually solicited from the referred to agencies prior to final approval of a proposed disposal program.

Oklahoma Water Resources Board, Rules and Regulations -

CHAPTER V

POLLUTION REMEDIES

500. INTRODUCTORY PROVISIONS

500.1 DEFINITION OF TERMS: For the purpose of carrying out these rules and regulations and in the performance of its duties, the Board relies upon the following definitions of terms:

(a) BOARD, whenever used herein, shall mean the Oklahoma Water Resources Board.

(b) PERSON means the State, any municipality, political subdivision, institution, public or private corporation, individual, partnership or other entity.

(c) WATERS OF THE STATE by law means all streams, lakes, ponds, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies of accumulations of water, surface and underground, natural or artificial, public or private, which are contained within, flow through, or border upon this State or any portion thereof, except privately owned reservoirs used in the process of cooling water for industrial purposes, provided that water released from any such reservoir into a stream system of the State shall be and become waters of the State. (926.1)

(d) POLLUTION by law means contamination or other alteration of the physical, chemical, or biological properties of any natural waters of the State, or such discharge of any liquid, gaseous, or solid substance into any waters of the State as will or is likely to create a nuisance or render such waters harmful or detrimental or injurious to public health, safety, or welfare; to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses; or to livestock, wild animals, birds, fish, or other aquatic life. (926.1)

(e) WASTES by law mean industrial waste and all other liquid, gaseous, or solid substances which may pollute or tend to pollute any waters of the State. (926.1)

(f) DISPOSAL WELL means any system of pipelines, conduits, tubing, pumps, holding tanks, and all other constructions, devices, appurtenances, and facilities used to convey, deposit, or discharge waste to a storage reservoir below land surface.

(g) DISPOSAL SYSTEM by law means a system for disposing of wastes and includes sewerage systems and treatment works. (926.1)

(h) TREATMENT WORKS by law mean any plant, disposal field, lagoon, dam, pumping station, incinerator, or other works used for the purpose of treating, stabilizing, or holding wastes. (926.1)

(i) SYSTEM by law means pipelines or conduits, pumping stations and force mains, and all other constructions, devices, appurtenances, and facilities used for collecting or conducting wastes to a point of ultimate disposal. (926.1)

(j) OPERATOR means the person responsible for the maintenance and operation of a disposal well and for keeping records and providing reports to the Board.

(k) MUD means mud of not less that thirty-six (36) viscosity (A.P.I. Full Funnel Method) and a weight of not less than nine (9) pounds per gallon.

(l) DESIGNATED AGENT means those governmental entities designated by the Board to distribute reference samples.

(m) HEAVY METALS include but are not limited to cadmium, chromium, copper, gold, iron, lead, manganese, mercury, nickel, silver, and zinc.

(n) MINERAL CHARACTERISTICS mean acidity, alkalinity (bicarbonate, carbonate, hydroxide), barium, boron, bromide, calcium, chloride, fluoride, iodide, magnesium, silica, sulfate, sulfide, sodium, and potassium.

(o) NUTRIENT CHARACTERISTICS means compounds of nitrogen and phosphorus.

(p) PHYSICAL CHARACTERISTICS include but are not limited to color, dissolved oxygen, hardness, oxygen demand (BOD, COD), pH, solids (dissolved, suspended, etc.), specific conductance, temperature, and turbidity.

(q) REFERENCE SAMPLE means water standards made up under controlled conditions to be used in the determination of laboratory testing reliability.

(r) TOXIC SUBSTANCES are those substances which are dangerous to human, animal, or plant life, and include but are not limited to arsenic, cyanide, detergents, oil and grease, pesticides, phenols, and selenium.

500.2 DECLARATION OF POLICY: Whereas the pollution of waters of the State constitutes a menace to public health and welfare, creates public nuisances, is harmful to wildlife, fish and aquatic life, and impairs domestic, agricultural, industrial, recreational and other legitimate beneficial uses of water, and whereas the problem of water pollution of this State is closely related to the problem of water pollution in adjoining states, it is hereby declared to be the public policy of this State to conserve the waters of the State and to protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish, and aquatic life and for domestic, agricultural, industrial, recreational and other legitimate beneficial uses; to provide that no waste be discharged into any waters of the State without first being given the degree of treatment necessary to protect the legitimate beneficial uses of such waters; to provide for the prevention, abatement, and control of new or existing water pollution; and to cooperate with other agencies of this State, agencies of other states, and the federal government in carrying out these objectives. (926.1)

500.3 LAWS: The statutory powers and duties of the Oklahoma Water Resources Board are contained in Title 82, Oklahoma Statutes:

§§926.1-926.13, Pollution Remedies;

§§931-942, Pollution Control Coordinating Act of 1968
(as amended in 1971);

§§1020.1-1020.22, Oklahoma Ground Water Act;

§§1085.1-1085.28, Oklahoma Water Resources Board (Water
Conservation Storage Commission),
Membership and Authority;

§1401 - Kansas-Oklahoma Arkansas River Basin Compact; and

§1421 - Arkansas-Oklahoma Arkansas River Basin Compact.

Under other statutes, the Board is the primary agency for water resources planning and development and the administration of water rights within the State.

500.4 WATER QUALITY STANDARDS: In accordance with the provisions of the Water Quality Act of 1965, P.L. 89-234, as amended by P.L. 92-500 (1972), and the Clean Water Restoration Act of 1966, P.L. 89-753, the State of Oklahoma prepared and adopted water quality standards for interstate and intrastate waters of Oklahoma on April 10, 1973.

530. SPECIAL REQUIREMENTS FOR INDUSTRIAL WASTE DISPOSAL WELL PERMITS

530.1 PROTECTION OF FRESH WATER AND OTHER NATURAL RESOURCES:

(a) An application for a disposal well permit shall be approved by the Board prior to the start of construction.

(b) The application shall be accompanied by the proposed plan for construction which sets out the steps to be taken to protect the fresh water and other natural resources.

(c) All applications for subsurface disposal wells shall be critically evaluated to determine that:

1. Alternative disposal measures have been explored and found less satisfactory in terms of pollution control;

2. Adequate evidence demonstrates that said disposal well will not interfere with present or potential use of natural resources nor result in other environmental hazards; and

3. The disposal system has been designed and constructed using the best available techniques, equipment, and design criteria.

(d) Any person who drills or authorizes such a well to be drilled without a permit shall be subject to penalties in accord with regulations of the Board and its enabling legislation.

530.2 QUALIFICATIONS OF DESIGNERS AND OPERATORS OF DISPOSAL WELLS:

(a) All plans and specifications for a proposed disposal well must bear the seal of a registered professional engineer who has proven to the Board's satisfaction his competence in designing a disposal well.

(b) All plats, surface and subsurface maps, stratigraphic sections, lithological descriptions, and stratigraphic cross-sections shall be prepared by a professional geologist who has proven to the Board's satisfaction his competency in the geologic aspects of designing a disposal well.

530.3 PRETREATMENT:

(a) All applications for disposal well permits shall be critically evaluated to determine that the best practical measures for pretreatment of wastes have been applied.

(b) Pretreatment shall render substances to be disposed of compatible with solids and liquids in the disposal zone.

530.4 EMERGENCY STORAGE FACILITIES:

(a) Emergency storage facilities shall be provided to enable the disposal well operator to shut down safely in the event of component failure.

(b) In the event a disposal well must be shut down because of component failure, the well operator shall notify the Board in writing within forty-eight (48) hours stating the nature of the problem and the estimated time required to resume disposal operations.

530.5 APPLICATION FOR DISPOSAL WELL PERMIT:

(a) An application for a permit to drill a new disposal well shall consist of the following:

1. Standard Waste Disposal Permit.

2. Disposal Well Questionnaire.

3. Plats showing every oil, gas, water, or disposal well and every "dry hole" or other artificial penetration deeper than twenty-five (25) feet within a one (1) mile radius of the proposed disposal well, together with the name and address of each operator and each land surface owner.

4. Schematic diagram of well showing:

   a. Total depth of all plugs used in the well.

   b. Depth of the disposal interval.

   c. Depths of the tops and bottoms of the casing and cement to be used in the well.

   d. Size and weight of the casing and tubing; depth of the packer.

5. Geology of the disposal zone, including a structure contour map of the top of the disposal zone and an isopachous map of the disposal zone.

6. A minimum of two stratigraphic cross-sections of the formations penetrated at right angles to each other shall be constructed.

7. A five-thousand dollar ($5,000.00) performance bond.

(b) Application for a permit to convert an existing well to a disposal well shall consist of the information required in Rule 530.5 (a) above plus:

1. All electrical surveys and gamma ray-neutron logs of the well.

2. A bottom-hole pressure test.

3. A fluid injectivity test showing injection pressure versus cumulative liquid volume for a minimum period of one (1) week after well is first started and every two (2) years thereafter.

4. A detailed lithological description of all formations penetrated, together with all available core data. A copy of the core report should be included stating the method used in the determination of the porosity and permeability figures.

5. The casing of a converted well shall be tested as specified in Rule 530.9 (b).

(c) Upon completion of a new well the information required in Rule 530.3 (b), Subsections 1, 2, 3, 4 and 5 must be submitted to the Oklahoma Water Resources Board.

(d) The applicant shall mail by certified mail or deliver a copy of the application with the accompanying plat and schematic diagram to the landowner on whose land the disposal well is to be located at last address on file in office of county treasurer and to each operator or lessee of record within one-half (1/2) mile of the subject well, on or before the date the application is mailed to or filed with the Board.

(e) The application shall be submitted in triplicate. One copy shall be given to the Oklahoma Corporation Commission for review and comment, one copy shall be returned to the applicant, and one copy shall be kept on file at the Board's office.

(f) A public hearing shall be held at which time any interested party may register a formal complaint against the issuance of the permit. After the hearing, the application will be submitted to the Board.

530.6 PERMIT CONDITIONS:

(a) A disposal well permit is issued for a period of five (5) years and may be renewed upon written application to the Board.

(b) A renewal application must summarize the preceding five years' activities. The summary must include:

1. The total amount of waste material disposed of.

2. The estimated number of cubic feet in the disposal zone saturated with the waste material.

3. Estimated areal extent of saturation.

(c) The permit is issued with the condition that no damage to natural resources shall occur as a result of any operations associated with the disposal well.

(d) Violations of any rules and regulations set forth in this document and/or permit shall be cause of forfeiture of the Performance Bond.

(e) A permit to operate a disposal well shall expire if the well is not in operation for a period of six (6) months.

(f) A permit which has expired for nonuse may be renewed upon written application to the Board and after a field inspection as specified in Rule 530.9.

(g) All disposal wells drilled and/or completed prior to May 9, 1972, shall submit Performance Bonds as required in Rule 530.5 (a), Subsection 7, by July 11, 1972.

(h) All disposal wells shall comply with these rules and regulations in all respects by November 14, 1972.

530.7 CONDITIONAL PERMITS:

(a) Certain special conditions may be imposed or allowed by the Board.

(b) Any such special conditions shall become a part of the permit.

(c) The disposal well operator will be given adequate time to adjust to any unusual changes or conditions required by the Board.

530.8 CONSTRUCTION OF WELL:

(a) A disposal well shall be completed, equipped, and maintained in a manner that will prevent pollution of fresh water, damage to sources of oil or gas, or danger to any natural resources.

(b) Disposal of industrial waste or similar substance shall be through adequate tubing and below a packer, which is strategically set so as to isolate the waste-receiving formation.

(c) Tubing and all surfaces coming in contact with the waste fluid shall be constructed of materials which are resistant to the corrosive effects of the waste.

(d) The annular space between tubing and production casing shall be filled with a noncorrosive fluid and shall be monitored continuously for changes in pressure.

(e) The maximum total gradient (disposal pressure and fluid pressure) of any industrial disposal well shall not exceed 0.75 pounds per square inch (p.s.i.) per foot of depth from land surface to the top of the disposal zone.

The casing shall be tested at 150 percent of its maximum design pressure or 300 p.s.i., whichever is greater, before operation of a disposal well.

(f) The surface casing shall be cemented from the surface down to a minimum of 50 feet below the lowest fresh-water-bearing zone.

(g) The cement used in the production string must be of a material that will not react chemically with the waste to be disposed of.

530.9 FIELD INSPECTION:

(a) After a disposal well permit has been issued and before operation begins, a field inspection by the staff of the Board will be made.

(b) At the time of inspection, the well casing shall be tested at 150 percent of design pressure or 300 p.s.i., whichever is greater.

(c) At the time of inspection, the well operator shall demonstrate methods of monitoring:

1. Disposal pump pressure.

2. Annular pressure.

3. Chemical and physical nature of waste material to be disposed of.

4. Weight of waste in pounds per cubic foot.

530.10 OPERATING REPORTS:

(a) A daily log shall be kept by the operator of the disposal well showing the following:

1. Well number, owner, and permit number.

2. Source of waste material.

3. Chemical and physical nature of waste material disposed of.

4. Amount of waste material.

5. Density of waste in pounds per cubic foot.

6. Disposal pump pressure.

7. Annular pressure between tubing and production casing.

8. Pressure and fluid-quality reports from monitoring wells where required.

This log shall be signed by the person responsible for maintenance and operation of said well and submitted monthly to the Board.

(b) Every six (6) months the disposal well shall be shut down for a period of twenty-four (24) consecutive hours for the purpose of conducting a formation pressure test. Results of this test shall be given to the Board. If a problem or failure is indicated, a pressure test will be made at the earliest possible time and the results presented to the Board. Any remedial (or emergency) work shall be commenced immediately. The Board will be informed of the operator's work and a final report submitted within ten (10) days following completion of such work.

530.11 ABANDONMENT AND PLUGGING OF WELLS:

(a) The owner and/or operator of any industrial disposal well shall be jointly and individually liable and responsible for the proper plugging of said well.

(b) The owner and/or operator of any disposal well not in operation for a period of six (6) months must either apply for a new permit as specified in Rule 530.6 (f) or immediately plug the well.

(c) Any well to be permanently abandoned shall be immediately plugged.

(d) The owner and/or operator of a disposal well shall notify the Board of his intention to plug. Written notification shall be received at least ten (10) days prior to the commencement of plugging operations.

(e) The Board's staff shall be given the opportunity to be present at plugging operations. The plugging operator shall notify the Board of the exact time during which all plugging operations will take place.

(f) Every well shall be plugged in such a manner as to permanently prevent the migration of any disposed substances out of the disposal zone as well as the migration of oil, gas, or salt water into or out of any productive formations by means of the well bore. Plugging shall also seal off all fresh ground water strata encountered in the well so as to prevent the entrance of salt water or the escape of fresh ground water by means of the well bore.

(g) Before any casing is removed from a well, all liquids shall be removed or displaced and the well filled with mud. As the casing is removed, the well shall be kept filled with mud.

(h) Any uncased hole below the shoe of any casing to be left in the well shall be filled with cement to a depth of at least fifty (50) feet above the shoe of the casing. If the well is completed with a screen or liner and the screen or liner is not removed, the well bore shall be filled with cement from the base of the screen or liner to a point at least fifty (50) feet above the screen or liner.

(i) Whenever production casing is severed and removed, the well bore shall be cemented from a point fifty (50) feet below to a point fifty (50) feet above the point of severance; provided that, if after such cement plug has been set, the same string casing is again severed in the process of removal, further cementing thereof shall not be required.

(j) All fresh-water zones encountered in the well shall be sealed off and protected by adequate casing extending from a point at least fifty (50) feet below the base of the lowest fresh-water zone to within three (3) feet of the top of the well bore and by completely filling the annular space behind such casing with cement. If the surface or other casing in the well meets these requirements, a cement plug may be set at least fifty (50) feet below the shoe of the casing to extend at least fifty (50) feet above the shoe of the casing. If the casing and cement behind the casing do not meet the requirements of this subsection, the well bore shall be filled with cement from a point fifty (50) feet below the base of the lowest fresh-water zone to a point fifty (50) feet above the shoe of the surface casing. The well bore shall, in all events, be filled with cement from a point three (3) feet below ground surface to a point thirty-three (33) feet below ground surface.

(k) All intervals between cement plugs in the well bore shall be filled with mud.

(l) Any "rat" or "mouse hole" used in the drilling of a well with rotary tools shall be filled with mud to a point eight (8) feet below ground level and with cement from such point to a point three (3) feet below ground level and then shall be filled in with earth above the top of the cement.

(m) The top of the plug of any plugged well shall show clearly by permanent markings, whether inscribed in the cement or on a steel plate embedded in the cement, the well number and date of plugging.

(n) Within fifteen (15) days after a well has been plugged, the owner or operator shall file a plugging record in duplicate with the Board. If a complete and correct log of the well is not on file with the Board, then the owner at the time of plugging shall furnish and file a complete and correct log thereof or the best information available. The well bond will be released only when the requirements of this rule have been met.

Oregon[1,2]

Anti-pollution was strengthened by the Oregon legislature in the 1967 session (ORS 449-075-449, 107). Underground disposal is included in the new definition of "disposal system". Disposal of wastes will be allowed only by a permit from the Department of Environmental Quality, and infractions of the rules may be subject to penalties provided in the law. The Department of Environmental Quality has jurisdiction over pollution of air, surface waters, and ground waters; the State Engineer has jurisdiction over appropriations and use of ground water, and the Department of Geology and Mineral Industries has jurisdiction over underground disposal of brine or salt water.

Regulations were passed in 1969 requiring all disposal wells in the lava terrain to be converted to acceptable disposal systems by January 1, 1975. The regulations also specify that permits for disposal wells be limited to a five-year period. Effluent waste must be treated in an approved manner before being injected into any underground formation. The new regulations specify well casings are to be properly cemented and injection monitoring devices to be installed.

Subdivision IV of the Sanitary Authority Regulation deals with the construction of disposal wells.

Unless otherwise specified Section 14-005 through 14-045 of this chapter of the Oregon Administrative Rules Compilation were adopted by the Sanitary Authority May 13, 1969, and filed with the Secretary of State May 15, 1969, as Administrative Order SA 41.

Construction and Use of Waste Disposal Wells -

14-005 DEFINITIONS - As use in these regulations unless the context requires otherwise:

(1) "Person" means the state, any individual, public or private corporation, political subdivision, governmental agency, municipality, industry, co-partnership, association, firm, trust, estate or any other legal entity whatsoever.

(2) "Sewage" means the water-carried human or animal waste from residences, buildings, industrial establishments or other places, together with such ground water infiltration and surface water as may be present. The admixture with sewage as above defined of industrial wastes or wastes shall also be considered "sewage" within the meaning of these regulations.

(3) "Wastes" means sewage, industrial wastes, agricultural wastes, and all other liquid, gaseous, solid, radioactive or other substances which will or may cause pollution or tend to cause pollution of any waters of the state.

(4) "Waste Disposal Well" means any natural or man-made hole, crevasse, fissure or opening in the ground which is used or is intended to be used for disposal of sewage, industrial, agricultural or other wastes; provided, however, as used in these regulations waste disposal wells do not include conventional seepage beds, tile fields, cesspools or landfills constructed and operated in accordance with State Board of Health rules and regulations or waste treatment or disposal ponds or lagoons constructed or operated under a permit issued by the State Sanitary Authority.

(5) "Approved Permit Issuing Agency" means a city, county, or other governmental entity which has been specifically designated by the State Sanitary Authority as the agency authorized to issue pursuant to these regulations permits for the construction, modification, maintenance or use of waste disposal wells within a designated geographical area.

14-010 POLICY. Whereas the discharge of untreated or inadequately treated sewage or wastes to waste disposal wells and particularly to waste disposal wells in the lava terrane of Central Oregon constitutes a threat of serious, detrimental and irreversible pollution of valuable ground water resources and a threat to public health, it is hereby declared to be the policy of the State Sanitary Authority to restrict, regulate or prohibit the further construction and use of waste disposal wells as a means of disposing of untreated or inadequately treated sewage or wastes as rapidly as possible in an orderly and planned manner.

14-015 CONSTRUCTION OF USE OF WASTE DISPOSAL WELLS PROHIBITED.

(1) After the effective date of these regulations, no person shall construct or place in operation any waste disposal well for the disposal of sewage without first obtaining a permit for said construction or operation of the waste disposal well from an approved permit issuing agency.

(2) After the effective date of these regulations, no person shall construct or place in operation any waste disposal well for the disposal of sewage from a system serving more than 25 families or 100 people or of wastes other than sewage without first obtaining a permit from the State Sanitary Authority.

(3) After January 1, 1975, no person shall maintain or use any waste disposal well for the disposal of sewage or wastes without a currently valid permit from an approved permit issuing agency or the State Sanitary Authority which specifically authorizes said maintenance or use.

It is the intent of this sub-section to phase out, by January 1, 1975, the use of waste disposal wells except for those which are scheduled to be replaced by sewers in accordance with an approved plan and time-schedule, and those which are operated under specific permit from the State Sanitary Authority pursuant to Section 14-045 of these regulations.

14-020 ISSUANCE OF PERMITS WITHOUT SANITARY AUTHORITY APPROVAL PROHIBITED. After the effective date of these regulations, no person shall issue permits for the construction, modification, maintenance or use of waste disposal wells unless they are at the time of issuance designated by the State Sanitary Authority as the approved permit issuing agency for the area for which the permit is sought.

14-025 WASTE DISPOSAL WELL PERMIT AREAS. Permits for construction, modification, maintenance or use of waste disposal wells may be issued only in those designated geographic areas for which a city, county or district, legally authorized to provide sewerage services for the area complies with the following conditions:

(1) Maintains on file with the Sanitary Authority a currently approved sewerage program including a plan and time schedule for providing collection, treatment and disposal of wastes.

(a) The time schedule must be designed to provide an approved sewerage system within the shortest time possible and unless it can be demonstrated to be nonfeasible shall at least comply with the following:

(A) Qualified consulting engineer to be hired by not later than July 1, 1969.

(B) Preliminary engineering report including a detailed financing plan and construction schedule to be submitted to the Sanitary Authority by not later than January 1, 1971.

(C) Start construction of the sewerage system by not later than August 1, 1971, after obtaining approval from the Sanitary Authority of detailed plans and specifications.

(D) Complete construction of the approved sewerage system by not later than January 1, 1980.

(2) Submits to the State Sanitary Authority, during the month of January each year, annual reports which demonstrate that reasonable progress is being made in implementing the approved sewerage program.

14-030 WASTE DISPOSAL WELLS PROHIBITED WHERE BETTER TREATMENT OR PROTECTION IS AVAILABLE. Permits shall not be issued for construction, maintenance or use of waste disposal wells where any other treatment or disposal method which affords better protection of public health or water resources is reasonably available or possible.

14-035 PERMIT CONDITIONS. Permits for construction or use of waste disposal wells issued by an approved permit issuing agency shall include, in addition to other reasonable provisions, minimum conditions relating to their location, construction or use and a time limit for authorized use of said waste disposal wells, not to exceed a period of five years. Construction and orientation of building sewers shall be compatible with the approved area sewerage plan.

14-040 ABANDONMENT AND PLUGGING OF WASTE DISPOSAL WELLS.

(1) A waste disposal well upon discontinuance of use or abandonment shall immediately be rendered completely inoperable by plugging and sealing the hole to prevent the well from being a channel allowing the vertical movement of water and a possible source of contamination of the ground water supply.

(2) All portions of the well which are surrounded by "solid wall" formation shall be plugged and filled with cement grout or concrete.

(3) The top portion of the well must be effectively sealed with cement grout or concrete to a depth of at least 18 feet below the surface of the ground, or whenever this method of sealing is not practical, effective sealing must be accomplished in a manner approved in writing by the State Sanitary Authority or the authorized permit issuing agent if functioning.

14-045 CONSTRUCTION OR USE OF WASTE DISPOSAL WELLS PROHIBITED AFTER JANUARY 1, 1980. After January 1, 1980, it shall be unlawful for any person to construct, maintain or use waste disposal wells for disposal of sewage or wastes unless said wastes have been previously treated by methods approved by the Sanitary Authority and further such treated wastes shall be discharged to waste disposal wells only if specifically approved and authorized by the Sanitary Authority.

It is intended that this section will permit consideration for approval by the Sanitary Authority of waste disposal to deep injection wells, constructed and operated in accordance with a carefully engineered program, and for disposal to waste disposal wells of adequately treated and disinfected effluents from large, efficiently-operated, municipal or county sewage treatment plants where continuous and effective surveillance and control of waste treatment and discharge can be assured so as to fully safeguard water quality and the public health and welfare.

Pennsylvania[1]

The Sanitary Water Board is the primary pollution control agency; it can declare the discharge of industrial wastes to be unlawful (35 P.S. 691.302) and require a permit for discharging waste (S.691.307). The Department of Health is the Board's enforcement agency (71 P.S. 8539). Article 600 of the Rules and Regulations of the Sanitary Water Board concerns itself with industrial wastes. Section 15 of this article is titled "Subterranean Disposal of Wastes". Paragraph D of that section reads:

> "Disposal of wastes into underground horizons will only be accepted as an abatement of pollution when the applicant can show by the log of the strata penetrated and by the stratigraphic structure of the region and it is improbable that such disposal will be prejudicial to the public interest, but any such acceptance will be conditioned and will not relieve the applicant of responsibility for any pollution of the waters of commonwealth which may occur, in which case such disposal shall be stopped forthwith."

A few of the conditions under which permits were issued are:

1. That no usable water or minerals are encountered while drilling the well.

2. That a continuing rock is present above the receiving horizon.

3. That the receiving horizon will be completely saturated with fluid.

4. That the formation fluid be under pressure. (The purpose being an indication that the formation does not "bleed" into another "horizon or formation".)

South Dakota[1]

South Dakota has no laws governing the subsurface disposal of industrial wastes other than oil and gas brines. The Water Pollution Committee may cause an investigation of suspected pollution (SDC 1960, Supp. § 61.0146).

Tennessee[2]

In accordance with the Tennessee Stream Pollution Control Law, Tennessee Code Annotated Section 70-301-70-319 and in particular Section 70-301 (Definitions) the term "waters" shall mean all streams, rivers, lakes, ponds, marshes, water sources, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water surface and underground, natural or artificial, public or private, which are contained within, flow through, or border upon the State of Tennessee or any portion thereof."

During the 1963 General Assembly meetings, the wording was changed to include the protection of groundwater as well as surface water from pollution. Since that modification the Tennessee Pollution Control Board, an agency of the State Health Department, has assumed the authority for controlling the discharge of industrial waste waters into groundwater formations.

Available information indicates that there are no specific regulations or forms used to monitor or process disposal wells.

Texas[2,15]

The regulation of municipal and industrial waste disposal now is the responsibility of the Texas Water Quality Board.

This is the result of an act of the 61st Legislature, Regular Session 1969, which is compiled as Article 7621b Vernon's Texas Civil Statutes.

Injection Well Act -

A BILL TO BE ENTITLED
AN ACT

> Amending Chapter 82, Acts of the 57th Legislature, Regular Session, 1961, as amended (Article 7621b, Vernon's Texas Civil Statutes), relating to the disposal of wastes into a subsurface stratum by injection well; revising and rearranging Article 7621b, Vernon's Texas Civil Statutes, to improve the structure of the Act; transferring certain functions under the Act from the Texas Water Development Board to the Texas Water Quality Board; providing for civil penalties and injective relief for violations of this Act; validating the actions of the Texas Water Development Board under the Act and requiring transfer of certain records to the Texas Water Quality Board; repealing that part of paragraph (a) of Section 21 of Article 8280-9, Vernon's Texas Civil Statutes, in conflict with this Act; providing severability; and declaring an emergency.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS

Section 1. Chapter 82, Acts of the 57th Legislature, Regular Session, 1961 (Article 7621b, Vernon's Texas Civil Statutes), as amended by Chapter 615, Acts of the 59th Legislature, Regular Session, 1965, is amended to read as follows:

"Section 1. SHORT TITLE. This Act may be cited as the Injection Well Act.

"Section 2. DEFINITIONS. As used in this Act, unless the context requires a different definition:

"(a) 'Board' means the Texas Water Quality Board;

"(b) 'Commission' means the Texas Railroad Commission;

"(c) 'Person' means individual, corporation, organization, government or governmental subdivision or agency, business trust, partnership, association, or any other legal entity;

"(d) 'Pollution' means the alteration of the physical, chemical, or biological quality of, or the contamination of, water that renders the water harmful, detrimental, or injurious to humans, animal life, vegetation or property, or to public health, safety, or welfare, or impairs the usefulness or the public enjoyment of the water for any lawful or reasonable purpose;

"(e) 'Industrial and Municipal Waste' is any liquid, gaseous, solid or other waste substance or a combination thereof resulting from any process of industry, manufacturing, trade, or business or from the development or recovery of any natural resources, or resulting from the disposal of sewage, or other wastes of cities, towns, villages, communities, water districts and other municipal corporations, which may cause or might reasonably be expected to cause pollution of fresh water.

"(f) 'Fresh Waters' means waters whose bacteriological, physical and chemical properties are such that they are suitable and feasible for beneficial use for the purposes permitted by law;

"(g) 'Casing' means any material utilized to seal off strata at and below the earth's surface;

"(h) 'Injection Well' means an artificial excavation or opening into the ground, made by means of digging, boring, drilling, jetting, driving or otherwise, and made for the purpose of injecting, transmitting, or disposing of industrial and municipal waste into a subsurface stratum; also a well initially drilled for the purpose of producing oil and gas when used for the purpose of transmitting, injecting, or disposing of industrial and municipal waste into a subsurface stratum; but 'injection well' does not include any surface pit, excavation or natural depression used to dispose of industrial and municipal waste.

"Section 3. INDUSTRIAL AND MUNICIPAL WASTES: APPLICATIONS TO BOARD.

"(a) Before any person commences the drilling of an injection well, or before any person converts any existing well into an injection well, for the purpose of disposing of industrial and municipal waste, other than waste arising out of or incidental to the drilling of or the producing of oil or gas, a permit therefor shall be obtained from the board. The board shall prepare suitable forms for making application which shall be available upon request without cost. The board shall require the furnishing of such information by an applicant as the board may deem necessary to discharge properly the duties imposed by this Act. An application for a permit to drill an injection well, or to convert any existing well to an injection well, shall be accompanied by a fee of $25.00 which shall be collected by the board for the benefit of the state.

"(b) Upon receipt by the board of an application in proper form and accompanied by the necessary fee for a permit to drill an injection well, or to convert an existing well to an injection well, the board shall cause an inspection to be made of the location of the proposed injection well to determine local conditions and the probable effect of the injection well, and shall cause an evaluation to be made to determine the requirements for the setting of casing, as provided in Section 5 of this Act.

"(c) The board shall also send copies of every application received in proper form to the Texas Water Development Board, the Texas State Department of

Health, the Texas Water Well Drillers Board, and to such other persons as the board may designate. The agencies and other persons to whom a copy of the application is sent may make recommendations to the board concerning any aspect of the application, and shall have such reasonable time to do so as the board may prescribe.

"(d) The board may hold a public hearing upon an application if it is deemed necessary and in the public interest, but otherwise, a public hearing is not required. Notice of any public hearing and its procedure shall be under such terms and conditions as the board may prescribe.

"(e) Any person applying to the board for a permit to inject industrial and municipal waste, other than waste arising out of or incidental to the drilling for or the producing of oil or gas, into a subsurface stratum shall submit with the application a letter from the commission stating that the drilling of the injection well and the injection of industrial and municipal waste into the subsurface stratum will not endanger or injure any oil or gas formation.

"Section 4. WASTES FROM OIL DRILLING: APPLICATIONS TO RAILROAD COMMISSION.

"(a) Before any person may commence the drilling of an injection well, or before any person may convert any existing well into an injection well, for the purpose of disposing of waste arising out of or incidental to the drilling for or the producing of oil or gas, a permit therefor shall be obtained from the commission. The commission shall require the furnishing of such information by an applicant as the commission may deem necessary to discharge properly the duties imposed by this Act and shall promulgate such regulations or orders as to notice and hearing as may be deemed proper and necessary.

"(b) Any person applying to the commission for a permit to inject waste arising out of or incidental to the drilling for or the producing of oil or gas into a subsurface stratum shall submit with the application a letter from the board stating that the drilling of the injection well and the injection of such waste into the subsurface stratum will not endanger the fresh water strata in that area and that the formation or strata to be used for such waste disposal are not fresh water sands. The commission shall, if requested by the board, require the filing of a log of the injection well.

"Section 5. ISSUANCE OF PERMIT; CASING OF WELL; RULES AND REGULATIONS. If the board or commission, as the case may be, finds that the installation of the injection well is in the public interest, will not impair any existing rights, and that by requiring proper safeguards both ground and surface fresh waters can be protected adequately from pollution, the board or commission, as appropriate, may grant the application in whole or in part and issue a permit with such terms, provisions, conditions and requirements as are reasonably necessary to protect fresh waters from pollution by industrial and municipal waste. Specifically, the board or commission shall require that the injection well shall be so cased as to protect all fresh waters from pollution by the intrusion of industrial and municipal waste. The casing shall be set at such depth, with such materials, and in such manner as the board or the commission may require. The board or the commission, in establishing the depth to which casing shall be installed, shall consider known geological and hydrological conditions and relationships, the foreseeable future economic development in the area, and the foreseeable future demand for the use of the fresh waters in the locality. The board or commission may also require the permittee to keep and furnish a complete and accurate record of the depth, thickness and character of the different strata penetrated in the drilling of the well. In the event an existing well is to be converted to an injection well, the board or commission may require that the applicant furnish an electric log or a drilling log of the existing well. A copy of every permit issued by the board shall be furnished by the board to the commission, the Texas

Water Development Board, the Texas State Department of Health, and the Texas Water Well Drillers Board. A copy of every permit issued by the commission shall be furnished by the commission to the board, which shall in turn forward copies to the other agencies named in the preceding sentence. The board and the commission each shall adopt rules, regulations and procedures reasonably required for the performance of the duties, powers and functions prescribed for each by this Act. Copies of any rules or regulations under this Act proposed by the board or the commission shall, before their adoption, be sent by each of these agencies to the other agency, and also to the Texas Water Development Board, the State Department of Health, the Texas Water Well Drillers Board, and such other persons as the originating agency may designate. Any agency or person to whom the copies of proposed rules and regulations are sent may submit comments and recommendations to the agency proposing the rules and regulations, and shall have such reasonable time to do so as the originating agency may prescribe.

"Section 6. FILING COPY OF PERMIT. Any person receiving a permit to inject industrial and municipal waste, shall, before injection operations are begun, file a copy of the permit with the health authorities of the county, city and town where the well is located.

"Section 7. ENFORCEMENT. Any person who fails to comply with the provisions of this Act, or with any rule or regulation promulgated by the board or the commission under this Act, or with any term, condition or provision in his permit issued pursuant to this Act, shall be subject to a civil penalty in any sum not exceeding One Thousand Dollars ($1,000.00) for each day of non-compliance and for each act of non-compliance, as the court may deem proper. The action may be brought by the board or the commission, as appropriate, in any court of competent jurisdiction in the county where the offending activity is occurring or where the defendant resides. Full authority is also given the board or commission, as appropriate, to enforce by injection, mandatory injunction or other appropriate remedy, in courts having jurisdiction in the county where the offending activity is occurring, any and all reasonable rules and regulations promulgated by it which do not conflict with any law, and all of the terms, conditions and provisions of permits issued by the board of commission pursuant to the provisions of this Act. At the request of the board or the commission, the attorney general shall institute and conduct a suit in the name of the State of Texas for injunctive relief or to recover the civil penalty, or for both the injunctive relief and civil penalty, authorized in this section. Any party to a suit may appeal from a final judgment as in other civil cases. The obtaining of a permit under the provisions of this act by a person shall not act to relieve that person from liability under any statutory law of the Common Law."

Sec. 2. Validation of Authorized Actions; Transfer of Records. All permits, orders, and rules and regulations issued, promulgated, or administered by the Texas Water Development Board under Chapter 82, Acts of the 57th Legislature, Regular Session, 1961, as amended (Article 7621b, Vernon's Texas Civil Statutes), and in effect on the effective date of this Act, are validated and remain in effect unless and until amended or superseded by order or other appropriate action of the Texas Water Quality Board, and shall be administered by and under the jurisdiction of the Texas Water Quality Board. The permits, orders, and rules and regulations issued, promulgated or administered by the Texas Water Development Board under that Act and such reports, records and other information, or copies thereof, as the Texas Water Development Board and the Texas Water Quality Board mutually agree are reasonably necessary to enable the Texas Water Quality Board to properly administer the permits, orders, and rules and regulations, and perform the responsibilities of the Texas Water Quality Board under this Act, shall be transferred to and become the responsibility of the Texas Water Quality Board.

Sec. 3. Repealer. To the extent that any duties and functions under Article 7621b, Vernon's Texas Civil Statutes, were transferred or assigned to the Texas Water Development Board by Section 8 of Chapter 297, Acts of the 59th Legislature, Regular Session, 1965 (compiled as Section 21 of Article 8280-9, Vernon's Texas Civil Statutes, and enumerated in Paragraph (a) of that Section 21), or to the extent that there is any conflict between said Section 8 of Chapter 297 and this Act, that part of said Section 8 of Chapter 297 is repealed.

Sec. 4. Severability Clause. The provisions of this Act are severable. If any word, phrase, clause, sentence, section, provision or part of this Act should be held to be invalid or unconstitutional, it shall not affect the validity of the remaining portions, and it is hereby declared to be the legislative intent that this Act would have been passed as to the remaining portions, regardless of the invalidity of any part.

Sec. 5. Emergency Clause. The importance to the public of the amendments in this Act creates an emergency and imperative public necessity demanding the suspension of the Constitutional Rule requiring bills to be read on three several days in each House, and the same is hereby suspended, and this Act shall take effect and be in force from and after its passage.

Procedures -

The procedures outlined indicate that application forms (GW-14) are sent to a prospective applicant upon request. They require that the application be submitted in triplicate together with a twenty-five dollar filing fee and a preliminary engineering report prepared by a registered professional engineer or professional geologist. The report would include but not necessarily be limited to the following information:

"1. An accurate plat showing location of proposed injection well.

"2. A map indicating location of water wells and all artificial penetrations (oil and gas wells, exploratory tests, etc.) of the proposed injection interval(s) in the general area of the proposed injection well. Reasonable diligence shall be used to locate such penetrations. Well and abandonment records (Railroad Commission Forms 2 and 4) for all exploratory oil and gas tests located within the area owned and operated by applicant should accompany map.

"3. Description of local topography and geology pertinent to injection program. Depth of deepest strata containing fresh water or water of suitable quality for potential beneficial development as determined by well development and/or electrical logs.

"4. A detailed description of the chemical, physical, and biological characteristics of the waste to be injected. Complete chemical analyses of all inorganic constituents should be reported in ppm or mg/l. If organic fractions are present, all such constituents should be reported in ppm, mg/l, as individual percentages by weight, or in other appropriate terms.

"5. The anticipated average and maximum rate of injection in gallons per minute or barrels per day. Estimated yearly volume of injected waste and anticipated life of project.

"6. Data on completion and operation of proposed injection well.

(a) Total depth of well.

(b) Casing -- size, grade, type, weight, and setting depth of all strings; size and type of tubing, name, model, and depth of tubing packer setting.

(c) Cement -- type and volume to be used on each casing string and calculated top of cement behind each string. Describe and give percent of all cement additives.

(d) Proposed injection interval(s) and perforations. This should include the interval(s) to be utilized initially and the entire zone requested for future development.

(e) Diagrammatic sketch of proposed well.

(f) Anticipated maximum and average well head injection pressures.

(g) Description of possible hydraulic fracturing and/or acidizing programs, if anticipated.

(h) Description of proposed injectivity tests.

"7. Characteristics of injection interval(s).

(a) Lithology, porosity, permeability, temperature.

(b) Natural reservoir fluid pressure and equivalent hydrostatic head; fluid saturation and chemical characteristics; and fracture gradient or critical input pressure.

"8. Compatibility of injected waste and formation fluids.

"9. Calculated rate of fluid displacement by injected waste and directions of dispersion.

"10. Description of program to monitor water quality in fresh water aquifers.

"11. Surface installations.

(a) Detailed description of pretreatment process and facilities to be used (include flow diagram if available.).

(b) Description of type of materials to be used in pretreatment facilities and transmission lines.

(c) Description and location of all waste retention ponds, if such are to be used in conjunction with the injection well.

"12. In the event an existing well is to be converted to an injection well, applicant should submit a complete electric log, all other logs or surveys performed on the well, and complete casing and cementing data."

A letter from the Railroad Commission stating that the drilling of such an injection well and the injection of such wastes into a subsurface stratum will not endanger or injure any oil or gas formation must accompany the application.

Whenever sewage injection is involved another application form (GW-15) is used. That application has to be accompanied by a letter from the County Pollution Control or Health Offices stating whether or not the operation of such an injection well is likely to be detrimental or injurious to public health, safety, or welfare.

No permits are final until the Board confirms that the construction and operation of the injection well and related facilities have been accomplished in accordance to the permit and any amendments thereto.

West Virginia[1,2,18]

The West Virginia Division of Water Resources of the Department of Natural Resources administers the disposal of industrial wastes. They do not have specific regulations governing subsurface disposal but would appear to apply the same regulations used relative to oil and gas field brines. (Articles 5 and 5A, Chapter 20 of the Code of West Virginia 1931, as amended.) Section 2, Article 5A under definitions of the Water Pollution Control Act reads as follows:

> "(h) 'Industrial wastes' shall mean any liquid, gaseous, solid or other waste substance or a combination thereof, resulting from any process of industry, manufacturing, trade or business, or from the development, processing or recovery of any natural resources........"

Chapter 20 was amended by the 1969 West Virginia Legislature to include the following items concerning disposal wells:

"Article 5A, Section 2, Definitions:

"(p) 'Disposal well' shall mean any well drilled or used for the injection or disposal of treated or untreated sewage, industrial waste or other wastes into underground strata;

"(q) 'Well' shall mean any shaft or hole sunk, drilled, bored or dug into the earth or into underground strata for the extraction or injection or placement of any liquid or gas, or any shaft or hole sunk or used in conjunction with such extraction or injection or placement. The term 'well' shall not have included within its meaning any shaft or hole sunk, drilled, bored or dug into the earth for the sole purpose of core drilling or pumping or extracting therefrom potable, fresh or usable water for household, domestic, industrial, agricultural or public use;

"Article 5A, Section 5. Added subsection a.7:

"(a.7) Operate any disposal well for the injection or reinjection underground of any industrial wastes, including, but not limited to liquids or gases, or convert any well into such a disposal well or plug or abandon any such disposal well.

"Article 5A, Section 7. Expanded subsection b:

"(b) The chief or his duly authorized representative shall conduct such investigation as is deemed necessary and proper in order to determine whether any such application should be granted or denied. In making such investigation and determination as to any application pertaining to any activity specified in subdivision (7) of subsection (a) of Section Five (20-5A-5) of this article, the chief shall consult with the director of the state geological and economic survey and appropriate officials of the State

> Department of Health, and all such persons shall cooperate with the chief and assist him in carrying out the duties and responsibilities imposed upon him under the provisions of this article and the rules and regulations of the board; such cooperation shall include, but not be limited to a written recommendation approving or disapproving the granting of the permit and the reason or reasons for such recommendation."

No new policy statements were passed relative to the industrial disposal wells. However, the Water Resources Division has issued a policy statement directing the discontinuance of the use of the Salt Sands for return of salt brine from oil well operation within one area of the state where significant salt contamination of ground water has occurred.

The director of the Division of Sanitary Engineering of the State Department of Health would have to approve any permit for activities related solely to sewage.

Applications for permits are obtainable from the Chief of the Division of Water Resources. The chief and his representatives would conduct such investigations deemed necessary for the approval of the application.

The present responsibilities regarding disposal wells are as follows:

a. The Department of Natural Resources - responsible for the preservation of surface and ground water purity.

b. The Department of Mines, Division of Oil and Gas - responsible for assurance of proper drilling, casing and cementing operations as well as for the protection of workable coal seams.

c. The Geological and Economical Survey - responsible for approval of the geological aspects of the facility and to the extent feasible, to determine possible cross-contamination through abandoned, unplugged wells.

d. The Department of Health - a review by the Sanitary Engineering Division to insure protection of potable water supplies.

Wyoming[1,7]

There are no state regulations governing the subsurface disposal of industrial wastes. Whenever questions of pollution are evident they are passed directly to the Health Department for review. Title 35, Chapter 4, Article 2, relates to the "protection of Public Water Supply". There is an advisory council appointed by the Governor and charged to "advise the State Department of Public Health in developing a comprehensive program for the prevention, control and abatement of new or existing pollution of the waters of the state".

Permits for disposal wells will be issued only with the full approval of the State Engineer, State Geologist, and State Health Inspector.

FEDERAL

Administrator's Decision Statement No. 5[17]

EPA Policy -

This ADS records the EPA's position on injection wells and subsurface emplacement of fluids by well injection, and supersedes the Federal Water Quality Administration's order COM 5040.10 of October 15, 1970.

Goals - The EPA Policy on Subsurface Emplacement of Fluids by Well Injection is designed to:

(1) Protect the subsurface from pollution or other environmental hazards attributable to improper injection or ill-sited injection wells.

(2) Ensure that engineering and geological safeguards adequate to protect the integrity of the subsurface environ-

ment are adhered to in the preliminary investigation, design, construction, operation, monitoring and abandonment phases of injection well projects.

(3) Encourage development of alternative means of disposal which afford greater environmental protection.

Principal findings and policy rationale - The available evidence concerning injection wells and subsurface emplacement of fluids indicates that:

(1) The emplacement of fluids by subsurface injection often is considered by government and private agencies as an attractive mechanism for final disposal or storage owing to: (a) the diminishing capabilities of surface waters to receive effluents without violation of quality standards, and (b) the apparent lower costs of this method of disposal or storage over conventional and advanced waste management techniques. Subsurface storage capacity is a natural resource of considerable value and like any other natural resource its use must be conserved for maximal benefits to all people.

(2) Improper injection of municipal or industrial wastes or injection of other fluids for storage or disposal to the subsurface environment could result in serious pollution of water supplies or other environmental hazards.

(3) The effects of subsurface injection and the fate of injected materials are uncertain with today's knowledge and could result in serious pollution or environmental damage requiring complex and costly solutions on a long-term basis.

Policy and program guidance - To ensure accomplishment of the subsurface protection goals established above it is the policy of the Environmental Protection Agency that:

(1) The EPA will oppose emplacement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate ground water resources or otherwise damage the environment.

(2) All proposals for subsurface injection should be critically evaluated to determine that:

(a) All responsible alternative measures have been explored and found less satisfactory in terms of environmental protection.

(b) Adequate preinjection tests have been made for predicting the fate of materials injected;

(c) There is conclusive technical evidence to demonstrate that such injection will not interfere with present or potential use of water resources nor result in other environmental hazards;

(d) The subsurface injection system has been designed and constructed to provide maximal environmental protection;

(e) Provisions have been made for monitoring both the injection operation and the resulting effects on the environment;

(f) Contingency plans that will obviate any environmental degradation have been prepared to cope with all well shut-ins or any well failures;

(g) Provision will be made for supervised plugging of injection wells when abandoned and for monitoring to ensure continuing environmental protection.

(3) Where subsurface injection is practiced for waste disposal, it will be recognized as a temporary means of disposal until new technology becomes available enabling more assured environmental protection.

(4) Where subsurface injection is practiced for underground storage or for recycling of natural fluids, it will be recognized that such practice will cease or be modified when a hazard to natural resources or the environment appears imminent.

(5) The EPA will apply this policy to the extent of its authorities in conducting all program activities, including regulatory activities, research and development,

technical assistance to the States, and the administration of the construction grants, State program grants, and basin planning grants programs and control of pollution at Federal facilities in accordance with Executive Order 11752.

Signed by William D. Ruckelshaus, Administrator, February 6, 1973.

Recommended Required Evaluation Data -

The Administrator's Decision Statement No. 5 on subsurface employment of fluids by well injection has been prepared to establish the Agency's position on the use of this disposal and storage technique. To aid in implementation of the policy a recommended data base for environmental evaluation has been developed.

The following parameters describe the information which should be provided by the injector and are designed to provide regulatory agencies sufficient information to evaluate the environmental acceptability of any proposed well injection. A potential injector should initially contact the regulatory authority to determine the preliminary investigative and data requirements for a particular injection well as these may vary for different kinds of injection operations. The appropriate regulatory authority will specify the exact data requirements on a case by case basis.

(a) An accurate plat showing location and surface elevation of proposed injection well site, surface features, property boundaries, and surface and mineral ownership at an approved scale.

(b) Maps indicating location of water wells and all other wells, mines or artificial penetrations, including but not limited to oil and gas wells and exploratory or test wells, showing depths, elevations and the deepest formation penetrated within twice the calculated zone of influence of the proposed project. Plugging and abandonment records for all oil and gas tests, and water wells should accompany the map.

(c) Maps indicating vertical and lateral limits of potable water supplies which would include both short- and long-term variations in surface water supplies and subsurface aquifers containing water with less than 10,000 mg/l total dissolved solids. Available amounts and present and potential uses of these waters, as well as projections of public water supply requirements must be considered.

(d) Descriptions of mineral resources present or believed to be present in area of project and the effect of this project on present or potential mineral resources in the area.

(e) Maps and cross sections at approved scales illustrating detailed geologic structure and a stratigraphic section (including formations, lithology, and physical characteristics) for the local area and generalized maps and cross sections illustrating the regional geologic setting of the project.

(f) Description of chemical, physical, and biological properties and characteristics of the fluids to be injected.

(g) Potentiometric maps at approved scales and isopleth intervals of the proposed injection horizon and of those aquifers immediately above and below the injection horizon, with copies of all drill-stem test charts, extrapolations, and data used in compiling such maps.

(h) Description of the location and nature of present or potentially useable minerals from the zone of influence.

(i) Volume, rate, and injection pressure of the fluid.

(j) The following geological and physical characteristics of the injection interval and the overlying and underlying confining beds should be determined and submitted:

(1) thickness;
(2) areal extent;
(3) lithology;
(4) grain mineralogy;
(5) type and mineralogy of matrix;

(6) clay content;
(7) clay mineralogy;
(8) effective porosity (including an explanation of how determined);
(9) permeability (including an explanation of how determined);
(10) coefficient of aquifer storage;
(11) amount and extent of natural fracturing;
(12) location, extent, and effects of known or suspected faulting indicating whether faults are sealed, or fractured avenues for fluid movement;
(13) extent and effects of natural solution channels;
(14) degree of fluid saturation;
(15) formation fluid chemistry (including local and regional variations);
(16) temperature of formation (including an explanation of how determined);
(17) formation and fluid pressure (including original and modifications resulting from fluid withdrawal or injection);
(18) fracturing gradients;
(19) diffusion and dispersion characteristics of the waste and the formation fluid including effect of gravity segregation;
(20) compatibility of injected waste with the physical, chemical and biological characteristics of the reservoir; and
(21) injectivity profiles.

(k) The following engineering data should be supplied:

(1) diameter of hole and total depth of well;
(2) types, size, weight, and strength, of all surface, intermediate, and injection casing strings;
(3) specifications and proposed installation of tubing and packers;
(4) proposed cementing procedures and type of cement;
(5) proposed coring program;
(6) proposed formation testing program;

(7) proposed logging program;
(8) proposed artificial fracturing or stimulation program;
(9) proposed injection procedure;
(10) plans of the surface and subsurface construction details of the system including engineering drawings and specifications of the system (including but not limited to pumps, well head construction, and casing depth);
(11) plans for monitoring including a multipoint fluid pressure monitoring system constructed to monitor pressures above as well as within the injection zones; description of annular fluid; and plans for maintaining a complete operational history of the well;
(12) expected changes in pressure, rate of native fluid displacement by injected fluid, directions of dispersion and zone affected by the project;
(13) contingency plans to cope with all shut-ins or well failures in a manner that will obviate any environmental degradation.

(i) Preparation of a report thoroughly investigating the effects of the proposed subsurface injection well should be a prerequisite for evaluation of a project. Such a statement should include a thorough assessment of:

(1) the alternative disposal schemes in terms of maximum environmental protection;
(2) projection of fluid pressure response with time both in the injections zones and overlying formation, with particular attention to aquifers which may be used for fresh water supplies in the future;
(3) problems associated with possible chemical interactions between injected wastes, formation fluids, and mineralogical constituents;

Safe Drinking Water Act[18]

The "Safe Drinking Water Act", Public Law 93-523, 93rd Congress, S.433, December 16, 1974, is an amendment to The

Public Health Service Act and is inserted in that act as Title XIV. This is the first Federal legislation that deals directly with subsurface injection and directly affects deep-well waste injection systems. Part C of Title XIV which relates to deep-well injection is as follows:

"PART C - PROTECTION OF UNDERGROUND SOURCES
OF DRINKING WATER

"REGULATIONS FOR STATE PROGRAMS

"Sec. 1421. (a) (1) The Administrator shall publish proposed regulations for State underground injection control programs within 180 days after the date of enactment of this title. Within 180 days after publication of such proposed regulations, he shall promulgate such regulations with such modifications as he deems appropriate. Any regulation under this subsection may be amended from time to time.

"(2) Any regulation under this section shall be proposed or promulgated in accordance with section 553 of title 5, United States Code (relating to rulemaking), except that the Administrator shall provide opportunity for public hearing prior to promulgation of such regulations under this section, the Administrator shall consult with the Secretary, the National Drinking Water Advisory Council, and other appropriate Federal entities and with interested State entities.

"(b) (1) Regulations under subsection (a) for State underground injection programs to prevent underground injection which endangers drinking water sources within the meaning of subsection (d) (2). Such regulations shall require that a State program, in order to be approved under section 1422 -

> "(A) shall prohibit, effective three years after enactment of this title, any underground injection in such State which is not authorized by a permit issued by the State (except that the regulations may permit a State to authorize underground injection by rule);
>
> "(B) shall require (i) in the case of a program which provides for authorization of underground injection by permit, that the applicant for the permit to

inject must satisfy the State that the underground injection will not endanger drinking water sources and (ii) in the case of a program which provides for such an authorization by rule, that no rule may be promulgated which authorizes any underground injection which endangers drinking water sources;

"(C) shall include inspection, monitoring, recordkeeping, and reporting requirements; and

"(D) shall apply (i) as prescribed by section 1447 (b), to underground injection by any other person whether or not occurring on property owned or leased by the United States.

"(2) Regulations of the Administrator under this section for State underground injection control programs may not prescribe requirements which interfere with or impede -

"(A) the underground injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production, or

"(B) any underground injection for the secondary or tertiary recovery of oil or natural gas, unless such requirements are essential to assure that underground sources of drinking water will not be endangered by such injection.

"(c) (1) The Administrator may, upon application of the Governor of a State which authorizes underground injection by means of permits, authorize such State to issue (without regard to subsection (b) (1) (B) (i)) temporary permits for underground injection which may be effective until the expiration of four years after the date of enactment of this title, if -

"(A) the Administrator finds that the State has demonstrated that it is unable and could not reasonably have been able to process all permit applications with the time available;

"(B) the Administrator determines the adverse effect on the environment of such temporary permits is not unwarranted;

"(C) such temporary permits will be issued only with respect to injection wells in operation on the date on which such State's permit program approved under this part first takes effect and for which there was inadequate time to process its permit application; and

"(D) the Administrator determines the temporary permits require the use of adequate safeguards established by rules adopted by him.

"(2) The Administrator may, upon application of the Governor of a State which authorized underground injection by means of permits, authorize such State to issue (without regard to subsection (b) (1) (B) (i)), but after reasonable notice and hearing, one or more temporary permits each of which is applicable to a particular injection well and to the underground injection of a particular injection well and to the underground injection of a particular fluid and which may be effective until the expiration of four years after the date of enactment of this title, if the State finds, on the record of such hearing -

"(A) that technology (or other means) to permit safe injection of the fluid in accordance with the applicable underground injection control program is not generally available (taking costs into consideration);

"(B) that injection of the fluid would be less harmful to health than the use of other available means of disposing of wastes or producing the desired product; and

"(C) that available technology or other means have been employed (and will be employed) to reduce the volume and toxicity of the fluid and to minimize the potentially adverse effect of the injection on the public health.

"(d) For purposes of this part:

"(1) The term 'underground injection' means the placement of fluids by well injection.

"(2) Underground injection endangers drinking water sources if such injection may result in the presence in underground water which supplies or can reasonably be expected to supply any public water system of any contaminant, and if the presence of such contaminant may result in such system's not complying with any national primary drinking water regulation or may otherwise adversely affect the health of persons.

"STATE PRIMARY ENFORCEMENT RESPONSIBILITY

"Sec. 1422. (a) Within 180 days after the date of enactment of this title, the Administrator shall list in the Federal Register each State for which in his judgment a State underground injection control program may be necessary to assure that underground injection will not endanger drinking water sources. Such list may be amended from time to time.

"(b) (1) (A) Each State listed under subsection (a) shall within 270 days after the date of promulgation of any regulation under section 1421 (or, if later, within 270 days after such State is first listed under subsection (a)) submit to the Administrator an application which contains a showing satisfactory to the Administrator that the State -

> "(i) has adopted after reasonable notice and public hearings, and will implement, an underground injection control program which meets the requirements of regulations in effect under section 1421; and
>
> "(ii) will keep such records and make such reports with respect to its activities under its underground injection control program as the Administrator may require by regulation;

"(B) Within 270 days of any amendment of a regulation under section 1421 revising or adding any requirement respecting State underground injection control programs, each State listed under subsection (a) shall submit (in such form and manner as the Administrator may require) a notice to the Administrator containing a showing satisfactory to him that the State underground injection control program meets the revised or added requirement.

"(2) Within ninety days after the State's application under paragraph (1) (A) or notice under paragraph (1) (B) and after reasonable opportunity for presentation of views, the Administrator shall by rule either approve, disapprove, or approve in part and disapprove in part, the State's underground injection control program.

"(3) If the Administrator approves the State's program under paragraph (2), the State shall have primary enforcement responsibility for underground water sources until such time as the Administrator determines by rule, that such State no longer meets the requirements of clause (i) or (ii) of paragraph (1) (A) of this subsection.

"(4) Before promulgating any rule under paragraph (2) or (3) of this subsection, the Administrator shall provide opportunity for public hearing respecting such rule.

"(c) If the Administrator disapproves a State's program (or part thereof) under subsection (b) (2), if the Administrator determines under subsection (b) (3) that a State no longer meets the requirements of clause (i) or (ii) of subsection (b) (1) (A), or if a State fails to submit an application or notice before the date of expiration of the period specified in subsection (b) (1), the Administrator shall by regulation within 90 days after the date of such disapproval, determination, or expiration (as the case may be) prescribe (and may from time to time by regulation revise) a program applicable to such State meeting the requirements of section 1421 (b). Such program may not include requirements which interfere with or impede -

"(1) the underground injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production, or

"(2) any underground injection for the secondary or tertiary recovery of oil or natural gas, unless such requirements are essential to assure that underground sources of drinking water will not be endangered by such injection. Such program shall apply in such State to the extent that a program adopted by such State which the Administrator determines meets such requirements is not in effect. Before promulgating any regulation under this section, the Administrator shall provide opportunity for public hearing respecting such regulation.

"(d) For purposes of this title, the term 'applicable underground injection control program' with respect to a State means the program (or most recent amendment thereof) (1) which has been adopted by the State and which has been approved under subsection (b), or (2) which has been prescribed by the Administrator under subsection (c).

"FAILURE OF STATE TO ASSURE ENFORCEMENT OF PROGRAM

"Sec. 1423. (a) (1) Whenever the Administrator finds during a period which a State has primary enforcement responsibility for underground water sources (within the meaning of section 1422 (b) (3)) that any person who is subject to a requirement of an applicable underground injection control program in such State is violating such requirement, he shall so notify the State and the person violating such requirement. If the Administrator finds such failure to comply extends beyond the thirtieth day after the date of such notice, he shall give public notice of such finding and request the State to report within 15 days after the date of such public notice as to the steps being taken to bring such person into compliance with such requirement (including reasons for anticipated steps to be taken to bring such person into compliance with such requirement and for any failure to take steps to bring such person into compliance with such requirement). If –

"(A) such failure to comply extends beyond the sixtieth day after the date of the notice given pursuant to the first sentence of this paragraph, and

"(B) (i) the State fails to submit the report requested by the Administrator within the time period prescribed by the preceding sentence, or

"(ii) the State submits such report within such period but the Administrator, after considering the report, determines that by failing to take necessary steps to bring such person into compliance by such sixtieth day the State abused its discretion in carrying out primary enforcement responsibility for underground water sources, the Administrator may commence a civil action under subsection (b) (1).

"(2) Whenever the Administrator finds during a period during which a State does not have primary enforcement responsibility for underground water sources that any person subject to any requirement of any applicable underground injection control program in such State is violating such requirement, he may commence a civil action under subsection (b) (1).

"(b) (1) When authorized by subsection (a), the Administrator may bring a civil action under this paragraph in the appropriate United States district court to require compliance with any requirement of an applicable underground injection control program. The court may enter such judgment as protection of public health may require, in the case of an action brought against a person who violates an applicable requirement of an underground injection control program and who is located in a State which has primary enforcement responsibility for underground water sources, the imposition of a civil penalty of not to exceed $5,000 for each day such person violates such requirement after the expiration of 60 days after receiving notice under subsection (a) (1).

"(2) Any person who violates any requirement of an applicable underground injection control program to which he is subject during any period for which the State does not have primary enforcement responsibility for underground water sources (A) shall be subject to a civil penalty of not more than $5,000 for each day of such violation, or (B) if such violation is willful, such person may, in lieu of the civil penalty authorized by clause (B), be fined not more than $10,000 for each day of such violation.

"(c) Nothing in this title shall diminish any authority of a State or political subdivision to adopt or enforce any law or regulation respecting underground injection but no such law or regulation shall relieve any person of any requirement otherwise applicable under this title.

"INTERIM REGULATION OF UNDERGROUND INJECTIONS

"Sec. 1424. (a) (1) Any person may petition the Administrator to have an area of a State (or States) designated as an area in which no new underground injection well may be operated during the period beginning on the date of the designation and ending on the date on which the applicable underground injection control program covering such area takes effect unless a permit for the operation of such well has been issued by the Administrator under subsection (b). The Administrator may so designate an area within a State if he finds that the area has one aquifer which is the sole or principal drinking water source for the area and which, if contaminated, would create a significant hazard to public health.

"(2) Upon receipt of a petition under paragraph (1) of this subsection, the Administrator shall publish it in the Federal Register and shall provide an opportunity to interested persons to submit written data, views, or arguments thereon. Not later than the 30th day following the date of the publication of a petition under this paragraph in the Federal Register, the Administrator shall either make the designation for which the petition is submitted or deny the petition.

"(b) (1) During the period beginning on the date an area is designated under subsection (a) and ending on the date the applicable underground injection control program covering such area takes effect, no new underground injection well may be operated in such area unless the Administrator has issued a permit for such operation.

"(2) Any person may petition the Administrator for the issuance of a permit for the operation of such a well in such an area. A petition submitted under this paragraph shall be submitted in such manner and contain such information as the Administrator may require by regulation. Upon receipt of such a petition, the Administrator shall publish it in the Federal Register. The Administrator shall give notice of any proceeding on a petition and shall act upon such petition on the record of any hearing held pursuant to the preceding sentence respecting such petition. Within 120 days of the publication in the Federal Register of a petition submitted under this paragraph, the Administrator shall either issue the permit for which the petition was submitted or shall deny its issuance.

"(3) The Administrator may issue a permit for the operation of a new underground injection well in an area designated under subsection (a) only if he finds that the operation of such well will not cause contamination of the aquifer of such area so as to create a significant hazard to public health. The Administrator may condition the issuance of such permit upon the use of such control measures in connection with the operation of such well, for which the permit is to be issued, as he deems necessary to assure that the operation of the well will not contaminate the aquifer of the designated area in which the well is located so as to create a significant hazard to public health.

"(c) Any person who operates a new underground injection well in violation of subsection (b), (1) shall be subject to a civil penalty of not more than $5,000 for each day in which such violation occurs, or (2) if such violation is willful, such person may, in lieu of the civil penalty authorized by clause (1), be fined not more than $10,000 for each day in which violation occurs. If the Administrator has reason to believe that any person is violating or will violate subsection (b), he may petition the United States district court to issue a temporary restraining order or injunction (including a mandatory injunction) to enforce such subsection.

"(d) For purposes of this section, the term 'new underground injection well' means an underground injection well whose operation was not approved by appropriate State and Federal agencies before the date of the enactment of this title.

"(e) If the Administrator determines, on his own initiative or upon petition, that an area has an aquifer which is the sole or principal drinking water source for the area and which, if contaminated, would create a significant hazard to public health, he shall publish notice of that determination in the Federal Register. After the publication of any such notice, no commitment for Federal financial assistance (through a grant, contract, loan guarantee, or otherwise) may be entered into for any project which the Administrator determines may contaminate such aquifer through a recharge zone so as to create a significant hazard to public health, but a commitment for Federal financial assistance may, if authorized under another provision of law, be entered into to plan or design the project to assure that it will not so contaminate the aquifer."

SECTION XI

APPENDIX I

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APPENDIX J

EPA REVIEW COMMENTS AND CONTRACTOR RESPONSE

As a result of EPA review of this document, there were a number of questions and issues raised as to the conclusions made versus those warrented based upon the available information. Additional clarifying data and information were provided.

This appendix is provided so that users of the large amount of information contained in this report have available this clarifying data and information. Included are the EPA review comments and the contractor's response to those comments.

EPA REVIEW COMMENTS

The contractor has provided a rather impressive document (more than 1,400 pages), containing an extensive compilation of information dealing with deep-well disposal. In general, the produced document responds to the research request by providing the information about the present state-of-the-art of deep-well injection.

Based on the report, there is sufficient information available covering geologic aspects to define potential injection areas, well design and well construction. However, information on the salaquifer hydrology is meager, except in some localized areas where there has been extensive oil well drilling or exploitation of subsurface brines for their mineral content.

Major gaps exist in knowledge dealing with reactions of the injected wastes with the receiving geologic formations, and in the area of microbiology of injection zone salaquifers - all of which is essential for evaluation of safety and environmental adequacy of deep-well injection.

Monitoring techniques in present form are adequate to detect equipment malfunctions, and at a specific point, a monitor well may detect waste passage within a reservoir. These techniques are ineffective, however, for continuous tracking of waste movement within a reservoir, of waste escape from a reservoir, or of vertical movement of fluid. It seems to me, that after a waste stream is injected underground, there is practically no control over what happens to it or where it goes (page 8).

In view of problems identified by the subject report, certain statements and conclusions in the Executive Summary and elsewhere tend to present a rather unrealistically rosy picture of the safety and environmental adequacy of deep-well injection. Some of the conclusions favoring well disposal of hazardous wastes are inadequately supported and documented. The examples are:

1. Conclusions that (#7, page 10) - "Deep-well injection systems for nearly all types of nonhazardous and hazardous industrial waste are a safe method of handling the waste if the systems are properly located, designed, operated, managed, and regulated." This statement could be misleading at the present state-of-the-art of deep-well injection due to the fact that, at this time, no universal criteria exists to define the proper location, design, operation, management and regulation of deep-well injection; and that - "Tentatively excluded as being safe for deep well injection if containment is questionable are 13 chemicals and their related compounds identified in the assessment section." In the case where the waste containment is questionable, well construction should not be considered, since practically all injected wastes, including such wastes as brine and sewage which are indicated by this report to be a potential or latent hazard, could create an environmental problem if they escape from the host zone and enter the groundwater.

2. Recommendation that (#13, page 15) - "The injection of hazardous waste should be permitted to continue until there is positive evidence that it is having a deleterious effect upon environment" - could lead to a high risk approach to hazardous waste disposal.

3. Recommendation that (#16, page 15) - "Alternative methods that are safe and economically feasible for treating hazardous wastes should be investigated for waste streams now being injected into subsurface reservoir, if: 1) The waste is shown to be escaping from the host zone, and 2) the waste is having a detrimental effect upon the environment." - Starting with an investigation after wastes have been shown to be escaping from the host zone and creating problems is not an environmentally sound practice.

An evaluation of the degree with which the produced document complies with the contract scope-of-work was difficult since the produced final report differs considerably from the suggested form.

For example, it was suggested that Section I provide data and information relative to the specific wells disposing primarily industrial wastes of hazardous or potentially hazardous nature; an assessment of each well's operation from an environmental point, and a discussion relative to the good and bad features of well design, installation, operation, etc. This section would also contain "the case histories" of selected deep-well operations and their performance assessment. In the produced report those subjects are scattered throughout five different sections or appendices.

The following comments apply to the above subject:

1. No formal assessment of the environmental effects of deep-well disposal was made. Instead of this, Table 3, (page 28-36) "Assessment of Operating Deep-Wells Receiving Hazardous Wastes," provides information by well ratings (A) - Acceptable; (L) - Limited acceptability; (M) - Marginal; (U) - Unsatisfactory), and defines the intraformational reactions (underdetermined; not unfavorable; unfavorable). However, nowhere in the final report is an explanation as to the criteria selection used to define intraformational reactions, or the rating system used to assess a certain well as "acceptable" or otherwise. That information is essential for future evaluation of deep-well injection.

2. Some wells listed in Table 2, (page 27), - "Identification of Wells Receiving Hazardous Wastes," and with complete information provided in Appendix D (page 449 up) - "Inventory of Industrial Waste Injection Wells in the United States," were not included in the assessment in Table 3 - see wells: AL-4, 5; FL 5; LA-3, 19, 26, 54, 66; TX-12, 23, 30, 58, 86, 97, 98.

3. There are several discrepancies in the data provided in Tables 2, 3, and Appendix D - detected by random selection. For example, some wells listed as used for disposal of chromium wastes in Table 2, (wells KS-3, 12, 13, 14, 18), are specified as injected with "brine" in Table 3, and in Appendix D, and have no chromium content listed, (except for KS-18 indicating "brine" with 3.8 ppm Cr^{+6}).

4. Are heavy metal wastes considered to be hazardous for deep-well injection? They are listed as hazardous in Table 2, (page 27) - "Indication of Wells Receiving Hazardous Wastes," but not included among the 13 waste streams (page 5 and 102), considered to be "hazardous for deep-well injection in any system."

The "case histories" of selected deep-well operations are the subject of Appendix E (page 1045 up) and Appendix F (page 1070 up). I have the following comments on the above subject:

1. Different symbols are used for wells described in "case histories," (well A, B,), many of them are operating wells, as compared with Table 2 and 3. Some well indexing codes can be found in the middle of the text, some not at all, so it is difficult or impossible to compare provided information with overall well assessment.

2. Two "case studies," Belle Glade, Florida and Wilmington, North Carolina, need a conclusion drawn from the research described and its impact on the deep-well operation. Also, an assessment of the wells' performance is not included. Are those wells still operating?

It was suggested that Section II provide an assessment of the presently available technology in regard to adequacy for disposal of the hazardous waste in a manner precluding environmental degradation. The good and bad points of the technique were to be covered as well as criteria for handling the wastes. The information dealing with the above subjects can be found in different sections of this report. I would like to indicate the following shortcomings of the report in dealing with the above subject:

1. Explain the criteria used for rating of an area's acceptability for deep-well injection, elaborated in Table 1 (page 17 up) - "Acceptability of Deep-Well Industrial Waste Injection to Environmental Regime." The discussion on page 2 - Executive Summary, indicates a ten point criteria as compared to Table 1, which uses a six point criteria.

2. What is the significance of seismic risk in the rating of an area's acceptability for deep-well injection? In evaluation of the geology of California, the high seismic risk was probably not considered (page 61). Also, the overall system design and construction of deep-well injection systems (including surface treatment, monitoring wells, etc.), corresponding to the degree of seismic risk, as recommended on page 61, cannot assure an environmentally sound system and operation, regardless of waste being injected (see documented case from Region VIII - Well A, Appendix E).
3. Limestone and dolomite may not always be satisfactory as confining strata, contrary to the claim on page 56, if untreated highly concentrated acid wastes are injected. It can create unfavorable intraformational reactions and eventually result in well failure (see documented case from Region IV - Well A, Appendix E).

This whole section is too speculative; Elaborate on the statement "Fortunately, potential host zones in many places are enclosed by hundreds and occasionally thousands of feet of impermeable strata which virtually ensures their segregation" (page 56).

4. Was the environmental impact of "artificial fracturing to increase permeability" of strata considered (page 61).

Another OSWMP need was a discussion of wastes from specific industries (i.e., probably mixed waste streams as opposed to a pure waste containing one component or compound), and the problems that may exist in managing these wastes via deep-well injection, in a separate section. A special listing of wastes that cannot be disposed into deep-wells under any conditions should also have been included.

I have the following comments on this section:

1. The characterization of wastes being injected into deep-wells was discussed in three different sections (Section I, III, V). The wastes characteristics and their impact on host zone environment were discussed only in general terms. No attempt was made to discuss the wastes and their suitability for disposal by deep-well injection using their origin or by specific industry.

2. The special list of wastes that cannot be disposed by deep-well injection under any conditions was not included into the subject final report. Only tentatively excluded from deep-well injection if containment is questionable were 13 chemicals and their related compounds identified on page 5 and 102 of this report.

It was problematic to determine to what degree the contractor had elaborated on OSWMP's comments to the Draft Report (see U. Huber memo of March 7, 1975), as the page and figure numbers have been changed. Some of the requests for clarification (which were traced), however, were not fully answered. Examples are:

1. Page I-102, now page 1096: Please clarify....:

   a. The statement that chloride does not undergo any geochemical or biochemical reaction,

   b. The technique of indicating reactivity by comparing changes in comparison of wastes before and after injection by "normalizing," - these statements were not clarified.

2. Explain the criteria used to select the wastes considered unsafe for deep-well injection on page I-195. The discussion on page 5 and 103 of the final report gives only a partial explanation.

3. The research projects considered to have the greatest potential for providing significant results in the area of protecting the environment from adverse effects were not identified, as requested.

The additional comments and suggestions for correction are listed below:

Page 11	#11 -- should be ... on groundwater quality ...
Page 11	#16 Sewage ... statement should clarify if it considers raw or treated sewage (treated sewage, especially after chlorination, has a very low bacterial content).
Page 17	Table 1 - what is the seismic risk for New York (EPA II), Ah/w. (?)
Page 41	Figure 2 - reference?
Page 44	Table 6 - Depth (inches, feet?)
Page 48	Figure 3 - reference?
Page 50	Figure 4 - reference?
Page 52	Figure 5 - reference?
Page 55	What is considered to be adequate buffer zone?
Page 61	Table 7 - reference?
Page 64	Figure 6 - reference?
Page 67	Figure 7 - reference?
Page 71	Figure 8 - reference?
Page 73/74	Figure 9 and 10 - reference?
Page 76	Chemical aspect ... not a common practice, in most cases wastes are injected rather without discrimination.
Page 80	Seim and Hulse (?) reference.

Page 81	Reference to mercury poisoning has no connection with deep-well injection.
Page 82	Injected waste will be greatly modified not only by microbial activities, but also by dilution and chemical reaction within the salaquifer.
Page 125	Figure 12; reference; depth (inches, feet?)
Page 126	Figure 13, reference?
Page 127	Figure 14; reference, injection rate (?) units
Page 128	Figure 15; reference, volume (liter, gallon)?
Page 129	Figure 16; reference, disposal quantity (liter, gallon)?
Page 130	Figure 17; reference, depth (inches, feet)?
Page 131	Table 14, references; type of surface treatment and volume not specified. This is necessary for cost comparison.
	Table 15; references, heading of table not clear.
Page 496	Unreacted HCl 99.9% (?); also presence of living organisms in this kind of waste is unrealistic.
Page 499	Hard to expect biological activity in waste pickling acid.
Page 521	pH = 74 (?)
Page 526	Same as page 499
Page 534	Expression 'no BOD as such?" (20,000 ppm Na OCl strongly oxidative, hardly any biological activity)
Page 644	Phenol alkalinity (phenolphthalein ?)
Page 967	Contradictive, waste was pretreated in bio-pond, so it should have some biological activity.
Page 1076	Don't see connection between referenced research and deep-well injection.
Page 1083	Figure 195; reference
Page 1085	Case study Belle Glade needs conclusion and evaluation of environmental impact

Page 1099	Figure 200; reference
Page 1104	Figure 201; reference
Page 1105	Figure 202; reference
Page 1109	Table 31; headings ... should be: 7 and 11 waste free. What is meaning of last line in Table 31?
Page 1119	Case study in Wilmington, N.C., requires conclusion. What is the impact of research on deep-well injection?
Page 1121	Figure 206; reference
Page 1122	Figure 207 and 208; reference
Page 1123	Figure 209; reference
Page 1124	Figure 210; reference

This completes the list of specific comments.

CONTRACTOR REPLY TO REVIEW COMMENTS

The information in this section was submitted by the contractor. It provides his detailed reply to the comments and questions resulting from the EPA review of the work.

Re: Page 2

In the introductory paragraph on page 2, ________* indicates that certain statements and conclusions in the executive summary and elsewhere have a tendency to present a rather unrealistically rosy picture of the safety and environmental adequacy of deep-well injection. The reviewer cites one conclusion and two recommendations as statements favoring deep-well disposal which are inadequately supported and documented. It was not the intent of the contractor's report to present deep-well disposal of hazardous industrial waste as an unequivocally and riskless environmentally safe method of waste management. Deep-well injection is a valuable tool for industry, although some risk is involved, and when properly used there is a definite place for it among the various schemes of waste management.

1. (Re: Conclusion No. 7, page 10) The reviewer is correct in stating that no universal criteria exists to define the proper location, design, operation, management and regulation of deep-well injection insofar as a precise number of metres per injection zone, an exact number of cubic metres per second injection rate, or a limiting number of pascals at which a hypothetical volume of fluid may be injected into a theoretically predetermined reservoir rock can be applied. However, once a daily maximum and minimum amount of waste to be injected is determined and a growth factor for the waste volume is established the proper location, design, operation, management and regulation of that particular well may be well defined. The determination of location of a particular deep-well is discussed under the heading "Geologic Aspects," and its sub headings. The importance of the feasibility study is indicated on page 47 under the heading "Geologic Aspects" and again on page 53 under the sub heading "Reservoir Requirements."

   The criteria cited for site determination are relative and cannot be given exact dimensions until the amounts of fluid to be injected are known. Once anticipated volumes and rates are established operating limits can be defined and the mechanical success or failure, as well as the environmental effect, of a system may be determined with a high degree of reliability during the feasibility study and before drilling is begun. However, in a few cases where data are insufficient or inconclusive to allow this determination from the available data an exploratory well must be drilled and injection tests made as part of the study. In such instances the expenses incurred for drilling and testing are part of the calculated risk necessary for an operator to define an acceptable injection zone. On page 53 under the heading "Reservoir Requirements" it is noted that the criteria determining location are considered relative quantities. Reliability in establishing injection volumes and rates, and capacity of reservoirs has been demonstrated both theoretically and

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*Names of reviewers have been omitted at their request.

1. (Cont.) empirically during many years of practical application in oil field and water well development. Extensive studies on this subject have been made by Van Everdingen, Van Poolen, Hubbert, and many others.

   Regarding the second part of No. 1 page 2--I agree that where containment of the injected fluid is questionable well construction should be neither considered nor permitted. This idea is clearly indicated under the heading Geological in the first paragraph on page 2. "...A reservoir so chosen will have the capability to contain safely, any waste that may be injected into it provided the injected volume does not exceed the available volume of the reservoir and injection pressures do not exceed critical formation pressures..." The idea is again expressed in the first paragraph on page 47. "...Waste of these types are the ones that should be considered prime materials for controlling deep-well injection and storage, if the deep-well method is proved safe and acceptable to receive them." (There is a typographic error, controlling should read controlled.) Page 53, paragraph 1, Reservoir Requirements repeats the thought, "...There is the universal requirement that the waste be confined to the disposal formation so that commercially valuable natural resources including fresh water be protected..." The idea again appears on page 68, paragraph 2, under ENGINEERING ASPECTS. "The initial concern in the planning, construction and operation of a deep-well management system is the protection of life and property as represented by potable waters and minerals of economic value which might be found beneath the surface of the earth." The idea is presented still another time in the first paragraph under CHEMICAL ASPECTS on page 76, "...Precautions must be taken so that the waste itself will not harm the environment, and that there will be no reactions; or, if any reactions do take place, they will not be harmful."

2. (Re: Recommendation No. 13, page 15) "...could lead to a high risk approach to hazardous waste disposal."

   There is an element of risk in the handling and disposal of any hazardous material regardless of the designed safety factors or degree of sophistication of the method involved. Recommendation No. 13 should be read with the host reservoir basic prerequisites (noted in No. 1, part 2, above) in mind. Recommendation No. 13 also should be read and interpreted in conjunction with Recommendation No. 15. A recommendation lending itself to a more concise interpretation may possibly have been developed by integrating Nos. 13 and 15 into a single recommendation. Nevertheless, the low concentration of many of these hazardous substances in most

Re: Page 2 (cont.)

of the high volume waste streams greatly reduce the possible damage risk potential. Prudent operating procedures and diligent supervision and monitoring by regulatory agencies would also reduce risk potential. A well designed and operated deep-well system can probably be run with only slightly higher risk potential than many of the surface treatment plants operating today.

1. (Re: Recommendation No. 13, page 13) "...Starting with an investigation after wastes have been shown to be escaping from the host zone and creating problems is not an environmentally sound practice." I agree that starting an investigation or study after the waste has escaped from the host zone is not an environmentally sound practice. The "if" escaped the editor's pencil and should better read "in case", or "in order to replace deep-well systems when", or "in order to systematically phase out troublesome or questionable deep-well systems when." The gist of the recommendation is that alternate methods of treatment should be investigated and be available as replacements for troublesome and unsound well systems. This is not intended to advocate an "after the fact" investigation, but to follow the thinking of paragraph (3) in the Goals section and paragraphs (1) and (3) in the policy and program guidance section of the EPA ADS No. 5 dated February 6, 1973.

Re: Page 3

1. "...Instead of this, Table 3, (page 28-36) "Assessment of Operating Deep-Wells Receiving Hazardous Wastes," provides information by well ratings (A) Acceptable; (L) Limited acceptability; (M) Marginal; (U) Unsatisfactory, and defines the intraformational reactions (undetermined; not unfavorable; unfavorable)..."

Note: to be added to remarks on Table 3 code page 36;PpH= Precipitate when pH is greater than =
Dr. Zuhair Al-Shaieb, geochemist, at the University of Oklahoma determined the intraformational reactions from the available injected waste stream information vs formation lithology and interstitial water. This was the first phase toward developing a detailed reaction matrix between waste, formation, and operating parameters. The matrix was not developed beyond the first phase because of time and budgetary limitation. Dr. Al-Shaieb based the first phase on "favorable" or "unfavorable" development of gas or precipitate between injected fluid and the formation parameters. Dissolution of SiO_2 was also noted in several cases where the condition was determined. During the preparation of the table the headings undetermined, unfavorable and not unfavorable were chosen. The

Re: Page 3 (cont.)

1. (cont.) first two were as determined by Dr. Al-Shaieb; the third, not unfavorable, was used in preference to Dr. Al-Shaieb's original "favorable" because it was believed that a reaction developing gas or a precipitate, although not necessarily damaging or developed to an unfavorable degree could, only in a few cases, possibly be considered as favorable. The assessment of the various wells as acceptable, unacceptable, etc., was done on an individual well basis, which is the method by which the operations must be evaluated. Two geologists, a chemist, a petroleum engineer and a biologist, (in addition to Dr. Al-Shaieb) reviewed the available data on each well listed, and assessment arrived at by consensus. Although there were many weighting factors used the principal consideration was the protection of potable water aquifers and the maintenance of reservoir integrity. General aspects related to this subject are indicated in the first four columns to the right of the Intraformational Reaction section. Important influencing parameters occupy the remaining six columns before the rating column.

   The information used for evaluation is generally summarized in Appendix D, pages 495-2044. Knowledge of the operating area and operating practices also were used in influencing the appraisals. If the situation appeared to exist the two categories, Insufficient Aquiclude and Suspected Fresh Contamination were sufficient in most cases to warrant an unsatisfactory rating. In reiteration the ratings were made by consensus of a multi disciplined committee reviewing the data available on each well. The ratings on the individual wells will change and each well must be reviewed on a regular basis. The review scheduling will not necessarily be the same for each well; annual review will suffice for many, while others will require semiannual or even quarterly review to assess their status properly. Each well must be assessed individually and in relation to all the parameters affecting its safe operation.

2. "Some wells listed in Table 2, (page 27),- ...,were not included in the assessment in Table 3 - see wells: AL-4, 5; FL-5; LA-3, 19, 26, 34, 66; Tx-12, 23, 30, 58, 86, 97, 98."

   Table 2 identified all wells; operating, plugged, or permitted and not operating; for which there was information available indicating that hazardous waste was being, had been, or would be injected. Table 3 identifies the wells receiving one or more of the 13 chemicals regarded as undesirable for deep-well injection. Perhaps the title would be better if it read "Identification of Wells Receiving One or More of the Thirteen Chemicals Considered Undesirable for Deep-Well Injection." We discussed several titles, most of which proved to be quite long and unwieldy - the shorter title chosen apparently is ambiguous and confusing.

Re: Page 3 (cont.)

2. (cont.) Information received after the table was prepared shows that TX 100 and 101 are injecting a waste stream containing 30 ppm acrolein which should include them in the table.

   Table 3 - Assessment of Operating Deep-Wells Receiving Hazardous Waste. This table is an assessment of the 209 deep-wells operating at the date of the report. (206 are listed, the remaining 3 are permitted under the same number with one or more of the listed wells). For clarity and to differentiate between Tables 2 and 3 the title for Table 3 may better have read, "Assessment of 209 Deep-Wells Operating in January 1975."

   The wells, referred to earlier, which appeared in Table 2 would not appear in Table 3 because none of them were operating wells at the time the data were prepared.

3. The discrepancies noted in Tables 2, 3 and Appendix D by random selection list wells KS-1, 12, 13, 14,18 showing disposal of chromium waste in Table 2, but containing only brine in Table 3 and Appendix D. The apparent discrepancies result from the contractor's interpretation of the available data. The key phrases are "cooling water" and "blow down water" which appear in all the "brine" wells listed in Table 2. It was common practice to add chromates to cooling waters, etc., to inhibit and retard the growth of bacteria, slimes, algae, etc., in the equipment. Comparing these "brine" wells with wells in the area showing chromium wastes being injected, and the operators of the chromium waste wells vs. "brine" well operators - I feel secure in saying that an analysis of the injected fluid of both type wells would show almost the same amount of chromium.

4. "Are heavy metal wastes considered to be hazardous for deep-well injection? They are listed as hazardous in Table 2, (page 27)." ...Table 2 has 14 headings. Thirteen of these headings are the chemicals listed as hazardous for deep-well injection in any system. The fourteenth heading, "Identified Only as Heavy Metals," was added because data received on many of the wells identified heavy metals in the waste streams, and many of these heavy metals are both toxic and hazardous and are included in the 13 listed chemicals when specifically identified. (Cu, Zn, Ga, Ge, Ag, Cd, In, Sn, Sb, Au, Hg, Tl, Pb, Bi, = heavy metals periodic table, Hodgman, C.D., Handbook of Chemistry and Physics, 31st Ed., Chem. Rubber Pub. Co., Cleveland, Ohio.)

Re: Page 3 (cont.)

5. (cont.) The probability of one of the listed toxic and hazardous metals being included in the industrial waste streams listing only "heavy metals is great enough to justify noting the wells injecting the heavy metals.

Re: Page 4

First Section:

1. "Different symbols are used for wells described in 'case histories,' (well A, B,)..." The letter code in "case histories" is used only to separate the case history summaries for each EPA Region. The code does not bear any relation to Tables 2 and 3, nor was it intended to.

   The material for the summaries was drawn from many sources including much from the experience of the contractor. Many of the sources, especially the BuMines Circulars identified their various examples by letter or number only. The contractor can identify most of the wells with certainty, but there is some question on several from the BuMines source. Inasmuch as the wells which were summarized and could not be positively identified, all the case histories were referred to only by letter identification in the report. It was decided that this would be better than having part of the wells identified and part of them unidentified.

   For reference the wells are identified as follows:

Region III

Well A (PA-2) Hammermill Paper Co., Erie, Pennsylvania

Well B (PA-1) Jones & Laughlin, Aliquippa, Pennsylvania

Region IV

Well A (FL-1 and FL-2) Monsanto Textile Co., Pensacola, Fla.

Belle Glade Appendix F (FL-3 and FL-4) Quaker Oats Co., Bell Glade Chemical Plant Belle Glade, Florida

Wilmington, N.C. Appendix F (NC-1, NC-2, NC-3 & NC-4) Hercules, Inc., Wilmington, N.C.

Re: Page 6 (cont.)

(First Section)
1. (cont.)

Region V

Well A (IL-1 and IL-6) Velsicol Chemical Company
Marshall, Illinois

Well B (IL-3) Jones & Laughlin Steel Co., Hennepin, Illinois

Well C (IN-1 and IN-2) American Cyanamide Co.
Michigan City, Indiana

Well D (MI-11) Ford Motor Co., Rouge Plant, Dearborn, Mich.

Region VI

Well A (OK-13) American Airlines, Inc., Tulsa, Oklahoma

Well B (TX-20) Diamond Shamrock Oil Co., Amarillo, Texas

Well C (TX-86) Ethyl Corp., Pasadena Plant, Harris, Texas

Region VIII

Well A (CO-1) U.S. Corps of Engineers, Rocky Mt. Arsenal, Colo.

Table 14 (page 131) Region VI

Well A (OK-13) American Airlines, Tulsa, Oklahoma

Well B (Tx-8, TX-14, TX-32) Celanese Chemical Co., Bay City, Texas

Region V

Well C (IN-8) Midwest Steel Co., Portage, Indiana

Well D (OH-4) Vistron Corporation, Lima, Ohio

The contractor had intended to include a greater number of case histories and all in considerably greater detail. Inasmuch as some inconsistancies and gaps in data were apparent and time did not permit refining the data to the desired degree the additional histories were not included.

Re: Page 4 (cont.)

(First Section, cont.)

2. "Two 'case studies' Belle Glade, Florida (Re: page 6, this reply) and Wilmington, N.C. (Re: page 6, this reply) need a conclusion drawn from the research described and its impact on deep-well operation..." The conclusions drawn from the Belle Glade, Florida, study are:

    1. The geologic conditions which were known in the area of the well site were not considered or ignored when designing the injection system.

    2. A poor completion was made inasmuch as the reservoir conditions were known, the waste to be injected was known, and the reactions between the two could be accurately predicted.

    3. The overlying aquiclude was breached by the injected acidic waste permitting some water from the host salaquifer and some injected waste to escape with the overlying aquifer.

    4. The monitor well system was effective and detected the invasion of the overlying aquifer.

    5. The recompletion of the injection well appears to have corrected the problem of fluid escaping from the host salaquifer.

    6. A point of weakness to the integrity of the system remains in the area breached in the overlying aquiclude.

    The impact of this study on deep-well operation is a re-emphasis that none of the preliminary data of the feasibility study can be ignored, and that system design must be compatible with the data of the study. The study also emphasizes the necessity of a good monitoring system as an integral part of the overall injection system.

    The performance of the well as originally completed was unacceptable in that it permitted a breaching of the overlying aquifer and escape of injected fluid and host reservoir fluid into the overlying aquifer.

    The Belle Glade well has been worked over and recompleted and is still operating on a seasonal basis.

    The conclusions drawn from the Wilmingron, N.C. wells are:

    1. The geologic and hydralogic conditions of the area were known.

Re: Page 4 (cont.)

(First Section, cont.)

2. (cont.)

    2. Mechanical failure of some wells in the system permited leakage of injected waste and host reservoir water into overlying aquifers.

    3. The monitor wells were effective in detecting movement of the injected fluid.

    4. The area is not hydrogeologically compatible with deep-well injection of waste.

The impact of this study on deep-well operation again emphasizes the need to consider all the data available in a feasibility study, and it condemns this and similar parts of the Atlantic Coastal Plains for future attempts at deep-well waste injection.

The performance of the wells was not good. The entire exercise appears to have been somewhat of a mess from beginning to end.

All the injection wells have been shut down. The monitor wells were maintained in operating condition, but their present status is not known.

Second Section:

1. "Explain the criteria used for rating of an areas' acceptability for deep-well injection, elaborated in Table 1 (page 17 up)..."

As is explained on page 1, paragraph 2 under Geological, -- "Table 1 ...is a summary of broad geomorphic areas of the contiguous United States and classifies them as having apparent geologic compatibility with deep-well injection and will, in most cases, serve to identify areas which may or may not be feasible for safe injection. Detailed investigation, however, must still be made for any given well site within an area rated as acceptable in the table." The table is intended for use as a quick area identifier to make an initial decision on the acceptability of an area for deep-well injection. The criteria of the table for an acceptable area are more than the ten shown as guidelines for an acceptable reservoir only. Two criteria, no poorly plugged wells nearby and compatibility between reservoir and injected waste, are not considered because they become, by the necessity to keep the table generalized and simplified, parameters of the detailed study. Eight of the reservoir criteria are used, to which are added main fresh water aquifers to penetrate proximity of mineral resource and seismic risk. The breakdown is as follows:

Re: Page 4 (cont.)

Second Section (cont.)

1. (cont.)

A. Reservoir availability - an area containing reservoir rocks which have (1) uniformity, (2) large areal extent, (3) substantial thickness, (4) high porosity and permeability, and (5) low pressure is considered to have reservoir availability. This does not qualify the reservoir in any way except to those 5 criteria. The letter code under the heading shows no reservoir available (NA), limited areas of availability (LA), and areas of relatively unrestricted availability (A).

B. Adequate salaquifer - this was selected as a separate criteria for the table because in some areas many reservoirs capable of accepting injected wastes contain potable water. Letter ratings NA, LA, and A same as for reservoir availability.

C. Adequate aquiclude - this was made a separate criteria for the table because many areas do not have adequate aquicludes. Separation from fresh water horizons is also given consideration with this criteria. Letter rating:NA, LA, and A same as for reservoir availability.

D. Main fresh water aquifers to penetrate - this category gives a range for the depth to aquifers containing total dissolved solids of greater than 1000 ppm.

E. Mineral resources - an important factor in the final consideration of an area for deep-well injection.

F. Seismic risk an important factor in the final decision of selection of an area and design of a system.

G. Rating - a, b, c, and d are the most heavily weighted criteria; e and f are influencing criteria. None of the criteria carry numerical ratings.

In the remarks column opposite North Carolina it should be noted "Injection Prohibited by State Regulations."

2. "What is the significance of seismic risk in the rating of an areas' acceptability for deep-well injection?..."

Seismic risk is an influencing factor in rating the acceptability of an area for deep-well injection. The seismic risk factor can rate an area unacceptable or poor without considering other factors. However, it is generally used in conjunction with other criteria and, of course, it has less weight and is of less importance as the indicated risk decreases, i.e. 3 is greater than 2 is greater than 1 is greater than 0.

Re: Page 6 (cont.)

Second Section (cont.)

2. (cont.)

The high seismic risk was considered in the cursory evaluation of the geology of California (page 51). The paragraph points out that reservoirs are available in the many small Tertiary basins, but, "...the speculation of many factors, such as possible contamination of future water supplies; contamination of oil and gas reservoirs, and triggering of active fault zones prevent these basins from being considered as attractive for deep-well injection of any industrial waste at this time..." It also points out that injection is being conducted successfully in the Great Valley which does lie within an area of less seismic risk than most of the rest of California.

The overall system design and construction of deep-well injection systems, corresponding to the degree of seismic risk will provide an environmentally sound system and operations to a very high degree, but it cannot assure an absolutely perfect trouble free and riskless operation; nor can such a guarantee be given for the present surface treatment method for industrial wastes.

Despite the preponderance of circumstantial evidence relating earth tremors to injection in CO-1 there still is held two diametrically opposed opinions as to whether the injection is really the cause of the tremors. Also the theory has been advanced that such induced slippage, if such is the case, might gradually relieve built up strain and prevent a possible impending shock of greater magnitude. However, once an operation, such as CO-1, has been identified as a cause of something undesirable, whether by fact or fiction, it automatically becomes the cause of every undesirable situation in the area. Nevertheless the operation did cease after the coincidental relationship between tremors and injection was established and seismic condition approached those prior to injection.

3. I feel that there has been a communication lapse in this section. Nowhere on page 56 is there a claim that limestone and dolomite always are satisfactory as confining strata. To the contrary, the statement is made, "...Limestone and dolomite may be satisfactory confining strata. However, these rocks often have fractures and solution channels so their adequacy must be determined in each case. ..."

Untreated highly concentrated acid wastes injected, neutralize fairly rapidly in a carbonate environment. (see Belle Glade study; documented case from Region IV - Well A., Appendix E; and Donaldson's study on acid neutralization in carbonate reservoirs.)

Re: Page 6 (cont.)

Second Section (cont.)

3. (cont.)

True, concentrated acid waste can create unfavorable intraformational reactions and eventually result in well failure. However, nowhere in the discussion of Well A - Region IV Appendix E is well failure indicated as more than a possibility. With 359 feet of section available for injection I conclude, from the data available, that any injection with or without a buffer, 30 feet below the top of the formation (Top 1360; casing shoe, 1390) was not too judicious a decision considering the type and volume of waste to be injected.

I cannot understand why, "This whole section appears to be speculative; ..." Five rather concise major points are made in the section, none of which appear too speculative as outlined in their original order below:

1) Vertical confinement of waste is important.
   a) to protect usable water
   b) to protect oil and mineral deposits
2) Effect of lateral waste movement on mineral resources is al[illegible] an important consideration.
3) Unfrac[illegible]ed shale, clay, slate anhydrite, gypsum, salt, marl, bentonite and similar low permeability lithologic types are considered good seals against vertical migration of fluids.
4) Limestone and dolomite may be satisfactory confining strata. Inasmuch as they often have fractures and solution channels their adequacy must be determined in each case.
5) Reservoirs are covered by hundreds and sometimes thousands of feet of impermeable strata in many places virtually ensuring their segregation.

Elaborate on the statement "Fortunately, potential host zones in many places are enclosed by hundreds and occasionally thousands of feet of impermeable strata which virtually ensures their segregation" (Page 56). Russell, (W.L.) (Principles of Petroleum Geology, McGraw Hill Book Co., New York, 590 pp, 1960) states that 3m-6m (10-20 feet) of shale overlying an oil reservoir is sufficient to effect a good seal. Of course that thickness should not be considered to have a sufficient safety factor to act as an aquiclude for a reservoir receiving injected wastes. Fortunately most of the areas have a sufficiently thick sedimentary section of interbedded and intercalated lithologic units separating the host reservoir and potable water aquifers and/or the surface of the ground that they are positively separated, e.g. in the Eastern Interior basin: 610 m to 1524 m (2000' to 5000') of alternating carbonates and clastics form the barrier; in the Mid-Continent 305 m to 915 m (1000' to 3000') of carbonates, evaporites and clastics form the overlying aquiclude. These general examples can be illustrated throughout the country or specific localized areas can be described.

Second Section (cont.)

6. "Was the environmental impact of 'Artificial fracturing to increase permeability' considered (page 61)." This table originally presented by Van Everdingen[16] (page 92 this report) and again by Wright[17] (page 92 this report) was intended only to show the effect of fracturing on improving permeability of the reservoir rock. To make a valid consideration of the impact of fracturing on the environment from the data presented in Table 7 the thickness of the aquiclude needs to be known as does its lithology as well as the proximity to potable water aquifers, hydrocarbon and economic minerals. If the aquiclude was composed of shale or clay 30 m (100') or greater in thickness the artificial fractures would probably die out within the aquiclude and close following a relaxing of injection pressure; in which case injected waste would not escape and environmental degradation outside the host reservoir would be essentially nil. If the aquiclude were relatively thin and a potable water aquifer lay above it, the probability that the aquiclude would fracture completely through and the water and waste from the host reservoir would enter the overlying aquifer causing contamination is high. However, these last two statements are only conjecture because many of the critical parameters needed to assess the situation correctly are missing.

General Statement
First Section

"Another OSWMP need was a discussion of wastes from specific industries..."

I would have included a discussion of wastes from specific industries had it been called for in the scope of work. Such a discussion probably would have been included voluntarily regardless of whether it had appeared in the "Scope of Work" if the time frame of the project had permitted it. An overall discussion of the problems involved in determining the effects and reactions of mixed waste streams as opposed to pure streams and streams of varying concentration is included in the Executive Summary under Chemical, pp. 307; CHEMICAL ASPECTS, p. 76; PROBLEMS OF ANALYZING TOXIC AND HAZARDOUS WASTE EFFECTS, p. 96-98; HAZARDOUS WASTE AND WASTE STREAMS, p. 98-101; and POTENTIALLY HAZARDOUS WASTE BEING INJECTED; p. 100-104.

I do not believe that a special listing of wastes that cannot be disposed into deep-wells under any conditions can be compiled unless there is an arbitrary selection based on the toxicity or persistance of the pure substance, disregarding reservoir conditions, etc., of the well site.

Re: Page 5 (cont.)

First Section (cont.)

1. [illegible] notes that characterization of wastes being injected into deep-wells was discussed in Sections I, III, and V. I believe she intended to note Sections I, III, and IV. Appendix C compliments Section IV. Section I is not intended as a discussion, but as the first order heading indicates, a summary. If it is accepted as that its purpose is fulfilled. Section III is a review of the basic principles and the interrelationship of the numerous disciplines involved in planning, constructing and safely operating a deep-well injection system. This section was developed in the report on the belief that it is vitally needed. The conclusion was reached during the gathering of the data for the project when the apalling lack of basic knowledge of some people deeply involved with the planning, operation, and regulation of these systems became apparent. Section IV and its complimentary Appendix C was the discussion of waste characterization.

   The wastes characteristics and their impact on host zones could be discussed only in general terms. It many instances enough data was not available to discuss the impact in specific terms. A detailed analysis of each well and the waste stream being injected into it must be made to be specific on the impact on the host zone. This must be done for each well and waste stream, and is valid only for the well and associated waste stream analyzed.

   A discussion of wastes and their suitability for disposal by deep-well injection using their origin or by specific industry has bery little meaning. A valid assessment of one well and waste stream at one locality would not be valid at a different location if the wastes were of the same origin or from the same industry, e.g. a concentrated sulfuric acid injected into a carbonate reservoir of limestone and dolomite, disregarding the composition of the conate water, would generally react with the host reservoir neutralizing fairly rapidly and producing carbon dioxide gas and precipitating calcium sulfate as well as lesser quantities of other reaction products which could or could not have adverse effects upon the system. The same effluent from the same source placed in an acceptable quartzarenite reservoir would have only minute amounts of calcareous material with which to react thereby limiting the dissipation of the acid waste almost entirely to dilution by the formation water. Again the same low pH effluent injected into a graywacke or subgraywacke reservoir would, in all probability, cause tremendous operating problems because of reaction between injected fluid and formation minerals; one of the first reactions probably being swelling clays causing partial or complete loss of permeability and initially manifesting itself by increasing injection pressures and decreasing volumes of fluids accepted. With the potential number of end reactions between a

Re: Page 5 (cont.)

First Section (cont.)

1. (cont.)

single effluent and varying lithologies the combinations expand rapidly when the parameters of temperature, pressure, time, formation water chemistry, variable effluent concentration, etc. are added. The first section, "Intraformational Reaction" of Table 3 was the first step in the development of a reaction matrix for effluent that had been, was being, and would be injected (when known and identified). Time frame and budget would not permit the expansion of the matrix beyond its initial step, so it was incorporated into Table 3. Origin or specific industry means little unless all parameters in the systems being compared are the same.

First Section:

2. "The special list of wastes that cannot be disposed by deep-well injection under any conditions was not included into the subject final report..."

I do not believe that list of wastes that cannot be disposed by deep-well injection under any conditions can be legitimately compiled without mentioning some modifying circumstances which define exceptions to the rule. If we accept the premise that containment is possible then the 13 chemicals and their related compounds should be permitted to be injected. If their containment within the host reservoir is questionable then they should be tentatively excluded from injection, because, should dissipation or neutralization occur within the host reservoir, and if an injected stream containing dilute quantities of any of the 13 chemicals escapes in concentrations at or less than those established as safe by the USPHS the prime reason for curtailing the operation would be for the escaping fluid and not the toxic effect of the originally injected chemicals. Another example of the basic reasoning for tentative exclusion at this time is the injection of acrolein. There was divided opinion on whether it should have been included on the list. Although highly toxic and hazardous, some of our chemical people believed that it is so highly reactive that its dissipation would be complete within such a short time following injection that it should not even be considered for the tentative exclusion list. However, I believe that there is sufficient reason to include it.

If we reject the premise of containment and conclude that the tentatively excluded chemicals present too great a hazard regardless of the concentration at which they are injected or reside in storage, then the list indicating tentatively excluded wastes may be accepted as the special list of wastes that cannot be disposed by deep-well injection under any conditions. I believe that the oil and gas industry has too many documented examples of

Re: Page 5 (Cont.)

First Section (cont.)

2. (cont.)
effective containment in original reservoirs and in secondary use of reservoirs for water, gas, and LPG storage to say that containment is neither feasible nor effective. I believe that the only way such a definitive list of wastes unacceptable for injection can be made, at this time, is to establish the list based on the toxicity of the prime substance and discard all other parameters.

Second Section:

1. "Page 1, 102, now page 1096: Please clarify...:
(a) The statement that chloride does not undergo any geochemical or biochemical reaction.

(b) The technique of indicating reactivity by comparing changes in comparison of wastes before and after injection by 'normalizing', these statements were not clarified."

Kaufman, Goolsby and Faulkner (Ref. 29, p. 1127 this report) state, "The sample collected after 75 days residence time has been 'normalized' to the composition of the native aquifer fluids, using chloride as a conservative parameter. A conservative parameter is one which does not undergo any subsequent geochemical or biochemical reactions. The actual composition can then be compared with the normalized composition. Significant positive or negative deviations from normalized composition indicate geochemical reactions and/or anaerobic degradation of the waste. The results are as follows...:" (see tabularized data p. 1097 this report.) Inasmuch as no organism metabolizes chloride and it did not react with the injected waste in this situation it was chosen as the conservative parameter. The exact water analysis to which the injected fluid had been 'normalized' by Kaufman et al. still is not known to me. If I get the information I will be pleased to forward it together with the method he used in 'normalizing' it.

Re: Page 6

Second Section:

2. "Explain the criteria used to select the wastes considered unsafe for deep-well injection on page I-195..." The wastes were selected by the toxicity of the pure substance, and as indicated under the heading POTENTIALLY HAZARDOUS WASTE BEING INJECTED, " Based upon toxicological data, degradability, persistence, solubility in water, potential reactions, corrosiveness, and environmental effect, a tentative list of chemicals might be considered unsafe for deep-well injection has been made. ..." Reference: Appendix C, waste characterization profiles, pp 297-492 and references for Appendix C, p 493.

Re: Page 6 (Cont.)

Second Section (cont.)

h. (cont.)

The list is considered tentative because the low concentration of these substances in many waste streams, futher diluted by mixing with reservoir water upon injection may preclude any toxic or hazardous effect. It also does not make the list definitive, but leaves it open for the addition or deletion of any materials at a later date.

With reference to D. Huber memo of March 7, 1975 concerning the omission of bromine pentafluoride from the profiles or 'unsafe' waste list. It is considered to be included in the Fluorides category on the tentative list and is not included in the waste characterization profiles because they represent wastes being injected into deep-wells. Bromine pentafluoride was not identified as one of those substances.

i. "The research projects considered to have the greatest potential for ... protecting the environment from adverse effects were not identified. ..."

Of all the research projects reviewed twelve are believed to have the greatest potential for providing significant results in the area of protecting the environment. Those projects identified relate only to the studies that can be applied to all deep-well systems. Projects with restricted operating or geographic application were not included although many had merit in their restricted scope.

None of the projects chosen are considered to be definitive, but all represent a great step toward clarifying some of the conditions about which little is known and which relate closely to successful safe operation of injection systems.

The projects believed to have the greatest potential to provide significant results in the area of protecting the environment from adverse effects are:

Biological Studies

B-2 The role of microorganisms in the decomposition of deep-well injected liquid industrial wastes

The objectives of this study was to develop techniques for sampling and isolating microorganism indigenous to deep aquifers as a necessary prerequisite to determinations of changes that may occur in microbial population resulting from waste water injection.

Second Section (cont.)
1. (cont.)
B-1 Organic aspects of deep waste storage

The objectives were to predict the reactions and interactions between certain organic wastes and aquifer components when organic wastes are placed in the subsurface, establish the organic water quality of several uncontaminated ground water aquifers of the United States, and define the effects chemical and biological reactions have on the distribution and movement of organic wastes in the subsurface.

C-6 Treatment and disposal of complex chemical wastes

The objective of this study was to develop and evaluate a surface or subsurface method for control of pollution from a complex chemical waste from a petrochemical complex, manufacturing alkyl resin and phenols. Also to develop methodology and/or testing techniques to permit projections of: (1) the fate of waste components, and (2) the waste assimilative capacity, of deep geological formations.

C-8 Consolidation of available subsurface saline water analyses

The objective of this research was to establish an automatic data processing reference system for subsurface saline waters in the Storet format, which can be utilized in establishing the sources of ground water and surface water pollution resulting from oil production, deep well disposal, inadequately plugged oil wells, etc. For example, information concerning subsurface saline waters from any area in the U.S. would be obtained rapidly with the system for use in comparison with a polluted water. The computer system could be used to plot water analysis diagrams for use in saline water intrusion studies, and predictions of possible pollution area can be made for use in pollution prevention.

C-10 Compatibility of subsurface reservoirs with injected fluid wastes

The research plan involved laboratory determination of the long-term effects (compatibility) upon the physical parameters of subsurface rock formations resulting from the disposal of liquid wastes in deep-well injection practices. Purpose is to determine the extent of change in volumetrics and permeability of disposal reservoirs which may limit the economic practicability of this disposal method.

Second Section (cont.)
1. (cont.)

C-11 Computer modeling of rock-water interactions

The objective of this project was to develop a computer model which accurately predicts the chemical effect on the subsurface environment when waste fluids, such as the effluent of typical industrial processes, are injected into an aquifer. The desired output of the model is (1) a detailed prediction of the chemical interaction between the injected fluid, the aquifer brine and the rocks; (2) the identity and amounts of products formed by reaction; (3) the amount and composition of material absorbed onto mineral surfaces; (4) the thermodynamics of the processes in terms of pressure, temperature and volume changes; and (5) their distribution in space and time. These in turn predict changes in porosity, permeability and other factors important to the hydrologic regime.

C-18 Spatial distribution of chemical constituents in ground water

The objective of this project was to understand the chemical reactions between water and earth materials; and to describe the field relationships between the chemistry of the water, the geologic and hydrologic environment, and to identify problems that are amenable to solution by application of chemical thermodynamics; to identify and measure the variables that control the environment; and to interpret the measurements within the theoretical framework provided by reversible and irreversible thermodynamics, thereby being able to predict the chemical and physical changes that occur within an aquifer owing to stresses imposed upon the hydrologic system which may be the result of natural or artificial recharge of good quality water from injection of waste water or from withdrawals of water supplies.

C-19 Chemical reactions at mineral surfaces

The objectives of this project was to conduct laboratory experiments using physical-chemical techniques to characterize surfaces and measure reaction rates at various temperatures. Also, it was to study effects of specific mineral surfaces on rates of such chemical reactions as hydroxide or carbonate precipitation, relating rate to nature and area of surface exposed, and determining rate constants and related numbers that can be used for design or evaluation of actual field operations. When solutes are introduced into a ground water system, as in artificial recharge or waste injection, chemical reactions may occur between introduced and native materials. The reactions

Second Section (cont.)
3. (Cont.)

E-19 (cont.)
may precipitate solids that interfere with water movement, generate gases or bring about various physical and chemical changes in the system surrounding the injection site. These changes may influence water movement and/or composition. Mineral surfaces tend to catalyze some of the more important chemical reactions but the effect is poorly understood.

However, the presence of fine-grained inert solid minerals has been found to accelerate strongly the polymerization of aluminum hydroxide in solutions to which aluminum has been added and pH is slightly below neutrality. The rate of polymerization is directly related to specific surface area of minerals present. Methods for measuring the surface areas have been compared and adapted for use with various mineral forms.

E-8 The effect of pore fluid pressure on friction on fault and joint surfaces

The objective of the investigation is to study the effect of pore fluid pressure on the friction characteristics of rock surfaces, particularly if through variation of the pore fluid pressure sliding can be induced under a given state of stress, inasmuch as the mechanism of friction along weakness planes in the earth crust is thought to play an important role in earthquakes, slope stability and movements around water reservoirs and fluid injection wells.

E-9 Mechanical and frictional behavior of rocks in fluid environment

The objective of this project was to investigate the control of faulting near waste injection wells by modification of rock surface hardness. This was to be accomplished by pretreatment of waste fluids prior to injection so that frictional resistance of the faulted rock surface is increased.

The influence of various aqueous and non-aqueous surface-active environments on the near-surface flow and flow-dependent frictional behavior of several simple minerals were investigated in the laboratory to develop simple and economic procedures for treating fluid wastes prior to injection so that the possibility of triggering earthquakes can be reduced.

Second Section (cont.)
3. (cont.)

E-16 Pressure fracture gradient problems in deep well waste disposal

The objective of this project was directed toward an evaluation of the relationship between pressure buildup in deep well waste disposal reservoirs and the fracture resistance of confining strata or aquicludes.

The investigation consisted of the following procedures: 1. Pressure buildup in disposal reservoirs in response to long-term injection of given volumes of waste was determined, assuming that permeability of the reservoirs diminished with time as a result of chemical reaction between the waste and native pore material. 2. The state of stress of reservoirs at various depths within the earth, the resulting fracture gradients, and the resistance to vertical fracturing of confining strata was determined. 3. Maximum permissible pressure or volume of injected waste over the projected life of a disposal system that will insure the confining strata will not be subjected to fracturing stresses. 4. A computer program was developed that will correlate pressure buildup with fracture resistance of confining strata, determine the elapsed time when injection must cease, and calculate capital investment and operating costs of disposal of given volumes of waste.

H-2 Use of precise ground water temperature measurement for detecting and tracking pollution spread in shallow basalt aquifer west of Melbourne

The objective of this project was to provide a cheap and simple technique for monitoring movement of polluted ground water in the vicinity of effluent disposal bores.

On the whole, the results of these research projects, which were in a form available for review, were somewhat disappointing. As was stated earlier these projects were initial attempts to investigate some of the many problems associated with deep-well injection. They are not definitive, but do provide departure points for future research.

Page ii #11 Agreed it should read "... on ground-water quality..." the "of" slipped past the editors; the hyphenated "ground-water" conforms with present EPA usage.

Page ii #16 "Sewage..." untreated and inadequately treated sewage is the principal concern. However, the persistence and virulence of viruses outside a host in untreated and partially treated sewage is conjecture. How long the viruses remain a hazard in untreated

Re: Page 6 (Cont.)

Page 11 #16 (cont.)
sewage is not known; and what is required in the way of minimum treatment to kill them is not known. Elkan (Personal Communication, 1974) said, they must be regarded as a hazard, Erlich and Leenheer (Personal Communication, 1974) do not believe this to be so. However, until it is established at what degree of treatment the viruses are rendered innocuous they must be considered as a potential hazard especially while there remains divided opinion among those persons with expertise on that subject.

Page 17 Table 1 The seismic risk for New York (EPA II), Ah/w is 2-3

Page 41 Figure 2 Reference: Louis R. Reeder and Associates after Wapora, Inc., 1974 (Ref. 12, p.46 this report)

Page 44 Table 6 Depth in feet

Page 48 Figure 3 Reference: Louis R. Reeder and Associates after Wright, 1968 (Ref. 12, p. 92 this report)

Page 50 Figure 4 Reference: after Donaldson, 1974 (Ref. 2 p. 91 this report)

Page 52 Figure 5 Reference: after Algermissen 1969 (Ref. 3, p. 91 this report) reference is shown on the included figure. Algermissen on figure should read Algermissen. Eastern Massachusetts and northwestern Maine should have fine screened dots of risk area 3.

Page 55 An adequate buffer zone will vary greatly and must be determined for each well. The two principal determinants are the thickness of the porous and permeable section receiving the injected fluid and the volume of fluid that is to be injected over the life of the well. Of the two, the thickness of the effective reservoir section is the most influential for any given volume of injected fluid.

Page 61 Table 7 Reference: Louis R. Reeder and Associates after Wright, 1968 (Ref. 12, p. 92 this report) (Louis R. Reeder and Associates metric notations)

Page 64 Figure 6 Reference: Louis R. Reeder and Associates after Donaldson, 1974 (Ref. 17, p. 92 this report) (Louis R. Reeder and Associates metric notations)

Page 67 Figure 7 Reference: Louis R. Reeder and Associates after Donaldson, 1974 (Ref. 17, p. 93, this report) (Louis R. Reeder and Associates metric notations)

Page 71 Figure 8 Reference: Louis R. Reeder and Associates

Page 73-74 Reference: after Wright 1968 (Ref. 12, p. 92, this report)
Figures 9 & 10

Page 76
Chemical Aspect......I guess that this is a comment on the first paragraph of the section.It seems to be the only place that it might vaguely relate. The observation is quite astute, but really irrelevant to the paragraph inasmuch as the paragraph is expressing the way a deep-well operation should be approached and conducted, and not the way many are now being operated.

Page 80
Selm & Hulse (7) Reference: Selm, R.P. and B.J. Hulse, "Deep Well Disposal of Industrial Wastes," Industrial Waste Conference, 14th, 1959 Proc., Purdue Univ. Engr. Bull., Vol. 44, No. 5, pp. 566-596, 1960.

Page 81 Agreed that the mercury poisoning reference: "Examples of mercury...high levels of mercury.[10]" is irrelevant to this paragraph, but the rest of the material is pertinent. This reference was repeated and one or two similar references were edited out of the draft and final copy. This one should have been cut too.

Page 82 Agreed that injected waste will be greatly modified not only by microbial activities, but also by dilution and chemical reaction within the salaquifer. Change within the salaquifer is covered under both CHEMICAL ASPECTS pages 76-82 and under CHARACTERIZATION OF WASTE pages 95-96. These sections also infer modification by dilution, but it is not spelled out.

Page 125
Figure 12
Reference: after Koenig 1964 (Ref. 1, p. 132, this report). The depth may be in feet, metres, or whatever units desired, as may the cost units. This apparently is not clear in the explanation on page 124.

Page 126
Figure 13
Reference: after Koenig 1964 (Ref. 1, p. 132 this report).

Re: Page 7 (cont.)

Page 127
Figure 14
Reference: Louis R. Reeder and Associates. Injection rate may be in whatever units desired, gpm, metres^3/sec., etc.

Page 128
Figure 15
Reference: after Koenig 1964 (Ref. 1, p. 132, this report). Volume may be in whatever units desired, cu. ft., barrels, gallons, metres^3.

Page 129
Figure 16
Reference: afte/ Koenig 1964 (Ref. 1, p. 132, this report). Quantity (volume) may be in wahtever units desired, gallons, barrels, litres, metres^3, etc.

Page 130
Figure 17
Reference: after Koenig 1964 (Ref. 1, p. 132, this report). Depth may be in whatever units desired, feet, metres, etc. All are relative units.

Page 131
Figure 18
Reference: after Wright 1969 (Ref. 3, p. 132 this report). Reference given in paragraph 1 "Cost Examples" page 130 of this report. The type of surface treatment and volume of fluid injected into the wells listed in Table 14 is as follows:

Plant A.= Volume approximately 500,000 gpd of paint remover, waste oil, wash water containing traces of chromates and cyanides. Surface treatment consisted of skimming, biological treatment and neutralization.

Plant B.= Volume approximately 550,000 gpd of acidic acid, chlorinated hydrocarbons, and other organics. Surface treatment was complete neutralization, but the exact methods are not known.

Plant C.= Volume approximately 400,000 gpd of sulfuric acid pickling liquor. Surface treatment was with lime, resulting in a very large amount of CaCO$_3$ to dispose of. The big factor in this case, in addition to the expense involved in surface treatment, was that they exhausted the usable land fill areas.

Plant D.= Volume approximately 230,000 gpd of ammonia, sulfate, cyanide, aldehydes, organic acids, and nitrites. Surface treatment was by incineration.

Page 131
Table 15
Reference: after Wright 1969 (Ref. 3, p. 132, this report). Reference given in paragraph 1 "Cost Examples", page 130 of this report. There may be a built in fog factor in the heading of this table. However, five people, with technical training and with varied experience at reading tables, when shown Table 15 for the first time, interpreted it correctly. Nevertheless, the situation may be clearified by the explanation of the heading that follows:

A. The title Deep-Well Facility Average Operating Cost seems to clearly describe what the table shows.

Page 131 (cont.)
Table 15

B. EPA Region – This should be clear to anyone working for or with the EPA, or anyone conducting an operation coming under the jurisdiction of the EPA. Figure 1, page 16 of this report outlines these regions. A footnote might be made referring to Figure 1, if greater clarity is needed.

C. Area – This indicates specific geomorphic – geographic areas and is necessary because EPA regions will often overlap two or more areas, and conversely a specific area may fall within two or more EPA regions. It is also necessary so as to identify average operating costs to specific areas. The code GL, MC, GC, is explained under "Cost Examples" on page 130, which is the facing page to this table.

D. No. Wells – This shows the number of wells used to get the averages for the figures in the remaining columns. The number of wells used for averaging in each area was determined by those of which both volume and cost data were available.

E. Cum. Inj/Well [m^3 (Gals.) × 10^6] – Average cumulative injection per well in millions of cubic metres or (millions of gallons). e.g. first line 1,950,000 m^3 (515,900,000 gallons).

F. Inj./Well/yr. [m^3 (Gals.) × 10^6] – Average injection per well, per year in millions of cubic metres or (millions of gallons). e.g. first line 236,000 m^3 (62,300,000 gallons).

G. Yearly Cost –[mils/m^3 (Gal.)] – The yearly operating cost in mils per cubic metre or (mils per gallon). e.g. first line 111 mils per cubic metre per year or (0.42 mils per gallon per year). It also might be expressed $0.111 ($0.00042) or 11.1¢ (0.042¢) both of which would be extremely clumsey to use in Table 15 in the amounts noted per unit volume.

Page 496 Unreacted HCl 99.9% (?) I believe that the 99.9% probably represents the percentage of the waste stream that is represented by HCl, while the remaining 0.1% is compound of the phenol, chloride, and dissolved organics which are shown by weight.

Re: Page 7 (cont.)

Page 496 (cont.)

By manipulating various combinations of input volumes and using the specific gravity given, the percentage by weight falls within a range of acceptable error to at least start with such an assumption, considering the many unknown in the data. These well data shown in Appendix D are gathered from many sources almost none of which can or will verify the accuracy of the data or the care taken in its preparation. We have been through a great amount of it and corrected many obvious errors of which we are aware, as well as adding data from more reliable sources. We have also updated and verified data with state agencies and well operators. However, we realize that there are still many data that are sketchy and not of the quality with which we would prefer to work.

Also noted: presence of living organisms in this kind of waste is unrealistic. Our data indicate that this effluent has a pH of less than 1.0 which would indicate a rather stout concentration. Nevertheless, as unrealistic as it may seem, living organisms can and do exist in this kind of waste. Ehrlich[1], refers to work by Brock[2] on the environmental limits for growth and reproduction of selected microorganisms which shows some organisms living in an environment of pH0 while others can survive in an environment of possibly pH 13. This was also mentioned when he (Ehrlich) presented his paper "Role of Biota in Underground Waste Management" at the Symposium on Underground Waste Management and Environmental Implications, in Houston, Texas, December 6-9, 1971. Ehrlich also discussed the extreme pH limits at which organisms can survive and propagate with our biologist John W. Field, Jr., when Field interviewed him at Menlo Park in August, 1974. Amstutz[3] has observed fungi growth in a well disposing of spent sulfuric acid with a pH of 2.8. He has also mentioned this same situation in personal communication.

1. Ehrlich, G.G., Role of Biota in Underground Waste Injection. Amer. Ass. Petrol. Geol. Mem. 18, pp. 298-307, 1972.

2. Brock, T.D., Principles of Microbial Ecology, Prentice Hall, Englewood Cliffs, New Jersey, 306 pp., 1966.

3. Amstutz, R.W., and L.C. Reynolds, Is the Earths Crust Going to Waste - Part II, Types of Fluids Injected and Treating Procedures, National Petrol. Refiners Ass. Mid-Continent Regional Mtg., (Wichita, June 12-13, 1968) Reprint MC-68-48, 8 pp., 1968.

Re: Page 7 (cont.)

Page 499 Hard to expect biological activity in waste pickling acid. -- See discussion for page 496.

Page 521 pH: 74. (?) typographic error escaped editing -- should read pH: 7.4.

Page 526 See discussion for page 496.

Page 534 Expression probably should be deleted from the well data sheet to avoid any further confusion. We had discussion on the usage of the phrase when the data were being compiled from the various sources. We really didn't like it then because we did not know just what was being said, but it made its way into the final copy without being clarified.

Page 844 Phenol Alkalinity (phenolphthalein?). The phenol alkalinity = 10 ppm cam from Warner's Survey of Industrial Waste Injection Wells, Vol. III, p. 189, 1972. WAPORA'S Compilation of Industrial and Municipal Injection Wells in the United States, Vol. 2, p. TX-27 (b) shows BOD = 170 mg/l and pH 8.2. The information on this well which we obtained from the file of the Texas Water Quality Board in September 1974 should have superseded that from secondary sources on our well data sheet. The TWQB data on the effluent collected at the well head on January 24, 1973, analyzed, and reported on February 14, 1973, as follows:

	PPM		PPM
Silica	Interference	(Illegible) O - PO_4	90
Calcium	44	Carbonate	0
Magnesium	21	Bicarbonate	510
Sodium	256	Sulfate	48
Potassium	44	Chloride	317
NH_3 - N	56	Fluoride	Interference
		Nitrate	=0.4

PH 6.7

DISSOLVED SOLIDS (sum) 1130
(this sum falls 256 ppm short of the TOTAL which equals the ppm sodium noted)

Phenolphthalein Alkalinity as $CaCO_3$	0
Total Alkalinity as $CaCO_3$	421
Total Hardness as $CaCO_3$	198

Re: Page 7 (cont.)

Page 967 Noted as contradictive because waste pretreated in biopond should have some biological activity. The information below identifies the waste stream results of bio-pond retention and calculated reaction of injected effluent presented by du Pont to the TWQB.

COMPOSITION AND CHARACTERISTICS OF THE WASTE

The waste from the Beaumont Works Plant consists of two streams of identical compounds but of different percentages. Below is shown a typical example of the composition of each stream and composite sample of the waste to be injected, indicating the range of the individual components after mixing.

Ion or Compound	Stream 1	Stream 2	Composite
HCN	2,000 ppm	200 ppm	2,000-3,000 ppm
Acetonitrile	ND*	ND	50- 100
Acrylonitrile	32	10	20
Acrolein	36	ND	30
Fumaronitrile	3,183	476	1,785
Nicotinonitrile	815 p	666 ppm	622
Malononitrile	2,994	136	1,511
Succinonitrile	503	3,759	2,049
Phthalonitrile	79	87	79
Ammonium Sulfate	25,000	200	50,000-90,000
Polymeric Nitriles	------	-----	30,000-40,000
Water	------	-----	Remainder
pH	6.5	5.5	6.0-7.0
Specific Gravity	------	-----	1.020-1.058
Viscosity	------	-----	1.02-1.05 centipoise @ 25° C.

* ND not detected

Effluent condition following bio-pond treatment is shown as follows:

	Before	After	Present Beaumont Discharge Permit
CN ppm	2.5	0.3	
NH_3 ppm	50	200	5
BOD ppm	700	25	20
COD ppm	1,300	570	200
Dissolved O_2 ppm	0	2	
Suspended Solids ppm	40	65	25

Page 967 (cont.)

The retention time in the bio-pond was 14 days. The effluent would not be suitable for discharge to the Neches River. Long-term chemical reactions occurring in the waste materials shown in Table I, lists by compound the expected reactions. In summary, the ammonium sulfate is expected to remain unchanged. The nitriles will be hydrolyzed first to amides and finally to the equivalent organic acid which will remain as its ammonium or sodium salt.

WASTE STREAM TO BE DISPOSED OF IN DEEP WELL

Component*	Reactions	Eventual Speculated Decomp. Product
1. $(NH_4) SO_4$*	None	$(NH_4)_2SO_4$
2. HCN*	Polymerization(1)	Polynitriles (see 3) Polyamides (see 4) Polyacids (see 5), NH_4+
	Addition to double-bonds	Acrolein cyanohydrin (see 6) Acetaldehyde cyanohydrin (see 8) Succinonitrile (see 13)
3. Polynitriles*	Hydrolsis	Polyamides (see 4), NH_4+
4. Polyamides*	Hydrolysis	Polyacids (see 5), NH_4+
5. Polyacids*	Salt formation	NH_4+ and Na+ salts of polyacids
6. Acrolein cyanohydrin*	Polymerization(1)	Polynitriles (see 3)
7. Acrolein*	Polymerization(1) Addition to HCN Addition to H_2O	Polyacrolein Acrolein Cyanohydrin (see 6) Hydroxy-propionaldehyde
8. Acetaldehyde cyanohydrin*	Polymerization(1)	Polynitriles (see 3)
9. Acetaldehyde*	Polymerization (1) Addition to HCN	Polyacetaldehyde Acetaldehyde cyanohydrin (see 8)
10. Acrylonitrile*	Polymerization(1) Hydrolyses Addition to HCN	Polynitriles (see 3) Acrylamide (see 11), NH_4+ Succinonitrile (see 13)

Re: Page 7 (cont.)

Page 967 (cont.)

11.	Acrylamide*	Polymerization(1) Hydrolysis	Polyamides (see 4) Acrylic Acid (see 12), NH_4^+
12.	Acrylic acid*	Polymerization(1)	Polyacids (see 5)
13.	Succinonitrile*	Hydrolsis	Succinamide (see 14), NH_4^+
14.	Succinamide	Hydrolysis	Succinic acid (see 15), NH_4^+
15.	Succinic acid	Salt formation	NH_4^+ and Na^+ succinate
16.	Fumaronitrile*	Polymerization(1)	Polynitriles (see 3)
17.	Fumaronitrile*	Hydrolysis	Fumaramide (see 18), NH_4^+
18.	Fumaramide	Hydrolysis Polymerization	Fumaric acid (see 19), NH_4^+ Polyamides (see 4)
19.	Fumaric acid	Polymerization(1) Salt formation	Polyacides (see 5) NH_4^+ and Na^+ fumarate
20.	Maleonitrile*	Polymerization(1) Hydrolysis	Polynitriles (see 7) Maleamide (see 21), NH_4^+
21.	Maleamide	Hydrolysis (1) Polymerization	Maleic acid (see 22), NH_4^+ Polyamides (see 4)
22.	Maleic acid	Polymerization(1) Salt formation	Polyacids (see 5) NH_4^+ and Na^+ maleate
23.	Nicotinonitrile*	Hydrolysis	Nicotinamide (see 24), NH_4^+
24.	Nicotinamide	Hydrolysis	Nacotinic acid (see 25), NH_4^+
25.	Nicontinic acid	Salt formation	NH_4^+ and Na^+ nicotinate
26.	Phthalonitrile*	Hydrolysis	Phthalamide (see 27), NH_4^+
27.	Phthalamide	Hydrolysis	Phthalic acid (see 28), NH_4^+
28.	Phthalic acid	Salt formation	NH_4^+ and Na^+ phthalate
29.	Acetonitrile*	Hydrolysis	Acetamide (see 30), NH_4^+
30.	Acetamide	Hydrolysis	Acetic acid (see 31), NH_4^+

Page 967 (cont.)

31.	Acetic acid*	Salt formation	NH_4^+ and Na^+ acetate
32.	Propionitrile*	Hydrolysis	Propionamide (see 33), NH_4^+
33.	Propionamide	Hydrolysis	Propionic acid (see 34), NH_4^+
34.	Propionic acid	Salt formation	NH_4^+ and Na^+ propionate

* Known to be present, the other components listed may be present in trace quantities.

(1) The products of polymerizations would be expected to be less soluble, and form insoluble solids, especially in the presence of brine.

Page 1076 Notation - that no connection could be seen between referenced research and deep-well injection.

Although Signor's research was directed toward artificial groundwater recharge it may be applied equally well to oil field pressure maintenance, injection for secondary recovery of petroleum, disposal of oil field brine, or deep-well injection of industrial waste.

The success of any fluid injection system or program, regardless of what name it is given, is subject to the limitations caused by whatever mechanisms degrade the hydraulic conductivity of the porous media through which the fluid is being injected. The reduction of hydraulic conductivity may be caused by suspended solids, bacterial growth, chemical reactions of dissolved solids with the porous media or native water, air entrainment or dissolution of gasses in the interstices of the porous medium. Equipment deterioration because of bacterial action also presents limitations in system design and materials available for use.

Generally, field experiments will develop data related to one major problem encountered. Because of the lack of control, field tests usually are not conducive to the quantitative determination of the relative effects of several combined factors. Consequently, field tests result in conclusions which sometimes appear to be reiterations of problem descriptions, according to Signor (Ref. 5, p. 1125, this report).

Because of a lack of systematic experimental results, and because a study of the factors affecting the success or failure of an injection system must be comprehensive in scope, additional theoretical and experimental investigations are necessary.

Re: Page 7 (cont.)

Page 1076 (cont.) Laboratory determinations of the physical, chemical, and biological relations and interrelations of these factors are essential for their application to the lithologic environment of proposed field installations. Although the reader without field operating experience may not immediately recognize the connection between the referenced research and deep-well injection, an experienced field operator would. The research is an attempt to find a workable solution to the operator's perpetual nightmare of pore clogging and equipment deterioration because of physical, chemical, or bacterial action.

Page 1083 Reference: Leenhur, J.A., and R.L. Malcolm (Ref. 21, p. 1127, this report).

Page 1085 Conclusions: The Lower Floridan aquifer is capable of yielding and accepting large quantities of fluids. In the Belle Glade area greater than 0.03 hm^3 (800 million gallons) had been injected seasonly prior to the compilation of data for our well inventory in 1974. This hot, acidic, and highly organic waste (pH 2.6-4.5, COD 6000-26,000 mg/l) would normally, be expected to neutralize within the host reservoir. The waste is partially neutralized almost immediately to a pH of 5.5 by dissolution of limestone. The presence of hydrogen sulfide, methane, carbon dioxide, and nitrogen confirms the anaerobic degradation of the organic waste starting near the well bore (Ref. 25, p. 1127, this report). However, while the acid effluent was still of high enough concentration, its reaction with the extremely pure carbonate aquiclude breached that barrier and permitted the effluent to escape into the Upper Floridan aquifer, and be detected by a shallow monitor well within 27 months after injection began.

Following the liquid escape into the upper aquifer from the injection well, it was worked over by cementing an eight inch liner between 1494' and 1938' and deepening the hole below the liner from 1939' to 2242' as an open hole for injection into the salaquifer. Although this remedial work-over and recompletion apparently has solved the problem situation we have seen no verification of this.

Callipering the bore of the recompleted well 10 months after the work-over showed a bridge at 1945' and a 15' hole corroded in the mild steel tail pipe between 1923' and 1945'. The choice of material for the tail pipe was not too good in this case. A different material with an oil or other type inhibited liquid cushion placed below the casing shoe would have prevented any situation such as the pipe corrosion and liquid escaping, and entering the formation above the bottom of the liner.

Page 1035 (cont.)

The escape of the injected effluent from the host aquifer (Floridan, lower part) into the brackish Floridan (upper part) through the dense carbonate confining beds should never have occurred. The geology and lithology of the region was well known and the type effluent that was to be injected was well known, as were the possible reactions between the two. There was very little left for speculation on the geologic feasibility for this system. However, it seems as if this vital information was slighted or overlooked when the injection well was being planned and designed. The second step toward compounding the effects of this oversight and non use of pertinent data was poor design and completion of the injection well. The results of injection could fairly well be predicted from a cursory inspection of the completion data and sketches. Proper use of the available geologic information and proper design and completion could have prevented this situation from developing.

The monitor wells were well placed and proved effective in detecting leakage from the host reservoir and travel of the injected fluid.

Impact: The geochemical effects associated with the waste movement within the host aquifer includes increased concentration of calcium, magnesium, organic carbon, COD and alkalinity; reduction in pH and in sulfate concentration; and the generation of considerable quantities of hydrogen sulfide (83 to 93 mg/l). Dissolution of the carbonate aquifer, anaerobic decomposition, and sulfate reduction within the subsurface environment have occurred. The presence of sulfate-reducing bacteria within the organic-rich subsurface environment was confirmed.

Although it was evident that anaerobic decomposition of the high temperature, organic, nutrient-rich waste is taking place within the subsurface environment of the Belle Glade injection area, the results of investigations to date are only qualitative. Quantitative interpretation is limited because of the lack of comprehensive chemical analysis of the contained water taken from several zones before waste injection began. This makes uncertain the relative significance to be given to mixing and dilution versus anaerobic decomposition as a presumed cause of decreases in waste concentration.

Analyses of samples from the shallow monitor well during the year of March 1971 through March 1972, suggested a relative stabilization of the geochemical reactions following the deepening and recompletion of the injection well. Geochemical changes previously mentioned were noticed in the deep monitor well 1000 feet from the injection well. No geochemical changes were noticed in a monitor well in the upper Floridan

Re: Page 7 (cont.)

Page 1085 (cont.) aquifer two miles from the injection well. Comparative analyses for this well span a period of 40 years. No pressure changes were noted in any of the wells. (Ref. 25, p. 1127, this report). No data on operations within the last three years was received for this well.

The general direction of groundwater movement in the host aquifer is southeast toward the Straits of Florida a distance of 64 km (40 mi). It is believed that the waste will be neutralized before it reaches the waters of the straits and will cause no environmental problems.

From the information available it is believed that the injected effluent will remain in the host aquifer. However, if there should be fluid escape, it would be expected to be by the original escape route. Changes and effects on the water in the upper aquifer might be expected to follow the pattern shown by the data on page 1094 and in Table 27, page 1095. If the shallow monitor well begins to show indications of a change, injection can be stopped and the fluid escaping into the upper aquifer should be neutralized and/or diluted within a short period of time without permanent damage to the invaded reservoir.

Re: Page 8

Page 1099 Figure 200 Reference: after Leenheer and Malcomb (Re: 20 & 21, p. 1127, this report)

Page 1104 Figure 201 Reference: after Leenheer and Malcomb (Re: 21, p. 1127, this report)

Page 1105 Figure 202 Reference: after Leenheer and Malcomb (Re: 20, p. 1127, this report)

Page 1108 Table 30; Reference: after Leenheer and Malcomb (Re: 20, p. 1127, this report). No reference noted on table, but referenced in text on page 1107.

Page 1109 Table 31; headings should be corrected to read: ... 7 and 11 waste free. The number 7 was inadvertently omitted. The meaning of the last line in Table 31 is: A ratio of contaminated (4+5) divided by uncontaminated (7+11) and should appear as:

$$\frac{\text{Contaminated (4+5)}}{\text{Uncontaminated(7+11)}} \quad 2.9\ldots$$

The ratio check except for Fe which shows 5.1 in the table, but calculates as 4.53.

Re: Page 8 (cont.)

Page 1119 Case study Welmington, N.C., conclusions: Because of the unfavorable hydrologic conditions and the failure of some wells in the system which permitted leakage into overlying aquifers, deep-well injection was unfeasible at Wilmington. Waste injection ceased in November, 1972, after the injection system had been replaced by a conventional waste treatment system. We believe that the results of this exercise could have been anticipated from the feasibility study, and determined without doubt by drilling a slim exploration hole. We have made several feasibility studies in the Atlantic Coastal Plain and have arrived at the conclusion that for the most part the Atlantic Coastal Plain is not conducive to the development of good safe deep-well injection systems.

The impact of the research on deep-well injection is twofold: it emphasizes the generally unfavorable conditions for deep-well injection in the Atlantic Coastal Plains, and it emphasizes the need to correctly use and interpret the available data in a feasibility study prior to a full committment on a deep-well project.

In addition much valuable information on the behavior of organic wastes in the subsurface environment has been obtained. Also directly related to the research and injection well tests is the legislation enacted in 1973 by the General Assembly of North Carolina prohibiting waste disposal by deep-well injection in that state. (Re: 28, p. 1128, this report)

Page 1121 Figure 206; Reference: Louis R. Reeder and Associates

Page 1122 Figure 207 and 208; reference: Louis R. Reeder and Associates

Page 1123 Figure 209; reference: Louis R. Reeder and Associates

Page 1124 Figure 210; reference: Louis R. Reeder and Associates